Department of Science and Agriculture

BARBADOS

AGRICULTURAL JOURNAL

Vol. 4, No. 1. January, 1935.

ADVOCATE CO., LTD.,—Printers & Bookbinders to the Government of Barbados.

Department of Science and Agriculture

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MANURIAL TRIALS WITH SUGAR CANE.

S. J. SAINT, M.Sc., Ph.D., F.I.C.

SECTION I.

THE EFFECT OF TIME OF APPLICATION AND AMOUNT OF NITROGEN AS SULPHATE OF AMMONIA ON THE YIELD OF PLANT CANE. (1932—34).

There is some difference of opinion amongst practical planters as to the best time, under Barbados conditions, of applying nitrogen in the form of artificial fertilizer. It is debatable whether a small addition of nitrogen should be made in the "Early Cane Manure" which is applied between six and eight weeks after planting the cane. Further, there appears to be no reliable evidence bearing on the question of the time of application of the main part of the nitrogen. This is applied after the rains commence, either in one dose (July) or divided and applied in two applications in, say, July and September.

This trial was therefore planned with the object of obtaining some information on these questions and, at the same time, to determine the effect on the yield of plant cane of increasing amounts of nitrogen as Sulphate of Ammonia.

CENTRES.

Two centres were selected for the trial, (a) a red soil centre with a high rainfall under average conditions, and (b) a black soil centre, with medium low rainfall, under average conditions.

PLAN.

The trial was laid out in the form of five randomised blocks. There were ten different treatments, particulars of which are given in Table I.

TABLE I.

TIME OF APPLICATION AND AMOUNTS OF NITROGEN AND POTASH APPLIED PER ACRE..

Plots.	January	July	September.
	lb. per acre.	lb. per acre.	lb. per acre.
1	100 lb. K_2O 15 lb. N.	25 lb. N.	...
2	100 lb. K_2O	40 lb. N.	...
3	100 lb. K_2O	20 lb. N.	20 lb. N.
4	100 lb. K_2O 15 lb. N.	65 lb. N.	...
5	100 lb. K_2O	80 lb. N.	...
6	100 lb. K_2O	40 lb. N.	40 lb. N.
7	100 lb. K_2O 15 lb. N.	105 lb. N.	...
8	100 lb. K_2O	120 lb. N.	...
9	100 lb. K_2O	60 lb. N.	60 lb. N.
10	...	...	...

Notes on Table I.

N = nitrogen applied as Sulphate of Ammonia.
K_2O = potash applied as Muriate of Potash.

It will be noted that there were three different amounts of Sulphate of Ammonia applied, equivalent to 40, 80 and 120 lb. nitrogen per acre respectively. This nitrogen was applied in three different ways, viz., (1) 15 lb. in January and the remainder in July, (2) all in July, and (3) equal amounts in July and September.

The size of each plot was 56 cane holes (approximately 1/30 acre) and the inside 42 holes were cut and weighed in the estimation of yield.

A representative sample of cane weighing approximately 100 lb. was selected for each different treatment from each block for analysis. One complete analysis of cane was carried out for each treatment and five analyses of each treatment were made for sucrose in the juice. The mean sucrose in juice figure was used in calculating the composition of the entire cane. The sucrose in juice figures were subjected to statistical analysis.

RAINFALL.

The total rainfall for the growing season 1932—34 for the black soil centre was 75.49 inches as compared with an average of 58.71 inches for the same months between the years 1890—1929. At the red soil centre, the rainfall was 101.65 inches for the same growing period as compared with an average of 74.44 inches for the same months between the years 1890—1929.

Inasmuch as the distribution of the rainfall on the yield of canes is of as great importance as the total amount, the distribution of the rainfall is shown in Figs. I and II.

It will be noted that the total rainfall was nearly 30 per cent. higher at the black soil centre than the 30-year average figure and about 36% higher than the average figure at the red soil centre. Reference to Figs. 1 and 2 shows that this excess rainfall fell mainly during the months of July to November, but it should also be noted that in both December 1932 and January 1933, the rainfall was well above the average.

It is of interest to record the effects of this rainfall on the general sugar cane crop of the island. As far as tonnage of cane was concerned, the black soil districts recorded somewhat similar yields to those of the previous crop which was grown on a well distributed rainfall which approximated in amount to the 30-year average figure. In the red soil districts, the yield of plant cane and ratoons was about 20% lower than the previous crop which was also grown on an average, but well distributed rainfall. Thus, it would appear that the rainfall between July and November 1933, in the red soil districts, was too great for the cane to make its optimum growth. Correlated with the high rainfall, of course, would be such factors as high soil moisture, lower temperatures and less sun.

The cane rapidly matured and the crop season of 1934 commenced and finished much earlier than usual. The principal feature of the crop season was the high sucrose content of the juice and all factories reported higher recoveries of sugar per ton of cane. The lower yields of cane in the field were, therefore, partly made up by higher recoveries in the factories, with the net result that the island crop was not much below the record one of the previous year.

Field observations indicated that few October shoots made their appearance during 1933 and this probably accounts for the rapid maturity and high sugar content of the cane which was noticed during the crop season.

The interesting conclusion which is apparent from a study of the conditions existing in the 1933—34 growing season is that, in the red soil districts, a rainfall between July and November which is 30% or more above the average, is more likely to result in a decreased than in an increased crop.

YIELD RESULTS.

The yield results in terms of tons of cane and sucrose per acre, for the means of five plots of each treatment for each centre, are set out in Table II.

TABLE II.

Plot No.	Treatment (per acre).				Mean Yield of five plots, (per acre.)			
	January.		July.	Sept.	Black Soil Centre.		Red Soil Centre.	
	lb. K_2O	lb. N.	lb. N.	lb. N.	Tons Cane.	lb. Sucrose.	Tons Cane.	lb. Sucrose.
1	100	15	25	...	28·9	9,999	34·3	12,837
2	100	...	40	...	27·2	9,614	33·6	12,260
3	100	...	20	20	24·4	8,582	33·8	12,459
4	100	15	65	...	34·7	12,546	34·1	12,589
5	100	...	80	...	34·7	12,109	34·1	12,757
6	100	...	40	40	30·6	10,580	36·6	13,452
7	100	15	105	...	38·1	13,578	33·2	11,895
8	100	...	120	...	39·4	13,963	36·6	13,394
9	100	...	60	60	34·9	12,543	35·0	12,334
10	100	...	...	...	19·6	6,755	32·1	12,058

Statistical Analysis.

A difference between the mean yields of 5 plots of 4.9 tons cane for the black soil centre or 3.2 tons cane for the red soil centre, has a 20:1 chance of being due to treatment.

EFFECTS OF 40, 80, AND 120 LB. OF NITROGEN AS SULPHATE OF AMMONIA.

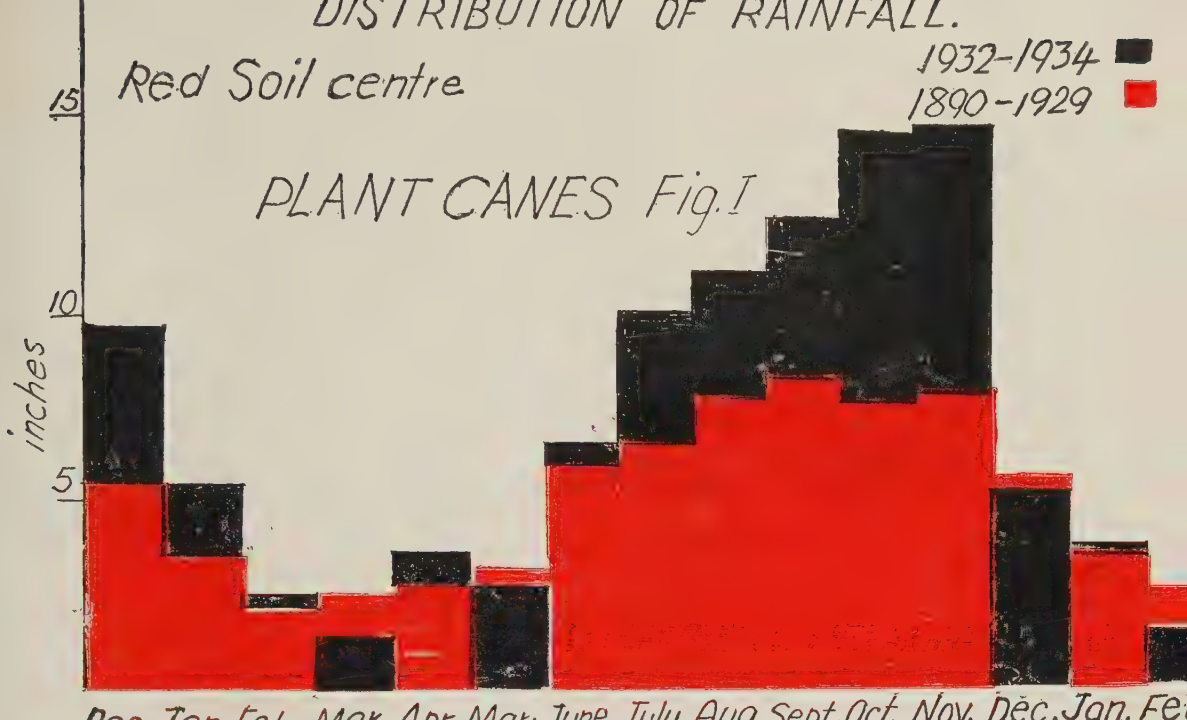
The effects of the different amounts of nitrogen on the yield can be considered more accurately if the effects of the different times of application are disregarded. In this way, the mean yields of fifteen plots can be taken; these are set out in Table III, together with the mean percentage sucrose in juice.

DISTRIBUTION OF RAINFALL.

Red Soil centre

1932-1934
1890-1929

PLANT CANES Fig. I



Black Soil centre

PLANT CANES Fig II

TABLE III.

EFFECT OF 40, 80 AND 120 LB. NITROGEN ON YIELD AND PER CENT. SUCROSE IN JUICE.

Treatment. Nitrogen.	Black Soil Centre. Tons Cane Mean of 15	Diff. from No-Nitrogen Plot.	Sucrose in Juice % Mean of 15	Diff. from No-Nitrogen Plot.	Red Soil Centre. Tons Cane. Mean of 15	Diff. from No-Nitrogen Plot.	Sucrose in Juice % Mean of 15	Diff. from No-Nitrogen Plot.
0	19·6	–	18·82	–	32·1	–	20·36	–
40	26·8	+ 7·2	19·18	+0.36	33·9	+1·8	20·66	+0·30
80	33·3	+13·7	19·32	+0·50	34·9	+2.8	20·43	+0·07
120	37·5	+17·9	19.37	+0·55	34·9	+2·8	20·48	+0·12

Statistical Analysis.

(a) A difference between the mean yields of 15 plots of 2.8 tons cane for the black soil centre and 1.8 tons cane for the red soil centre has a 20:1 chance of being due to treatment.

(b) A difference between the mean per cent. sucrose in the juice from 15 plots of 0.20 per cent. for the black soil centre and 0.33 per cent. for the red soil centre has a 20:1 chance of being due to treatment.

CONCLUSIONS.

BLACK SOIL CENTRE.

The successive additions of nitrogen, as Sulphate of Ammonia have had very marked effects on the yield of cane. The first 40 lb. nitrogen has increased the yield by 7.2 tons cane; the second 40 lb. nitrogen has given a further increase of 6.5 tons cane and the third 40 lb. nitrogen has resulted in a further increase of 4.2 tons cane.

It can be concluded that this particular field was deficient in available nitrogen and an application of Sulphate of Ammonia equivalent to 120 lb. nitrogen was a profitable application under the prevailing climatic conditions. In this connection, it should not be forgotten that the rainfall at the black soil centre approximated to the forty- year average rainfall figure of the red soil centre—an unusual occurrence.

The nitrogen plots also show a significant increase in the per cent. sucrose in the juice over the no-nitrogen plots. This is a somewhat surprising result, in-

asmuch as all the results which have been obtained on ratoon cane to date, show that additional applications of nitrogen have a depressing effect on the sucrose in the juice. This difference may be due to the shorter growing period of ratoon cane which, with excessive nitrogenous manuring, is unable to become fully mature and ripe by the time of cutting. As already pointed out, however, the 1934 crop season was marked by the maturity of the cane and the consequent richness of the juice.

RED SOIL CENTRE.

At the red soil centre the no-nitrogen plot gave a yield equivalent to 32.1 tons of cane per acre, showing that the soil was by no means deficient in available nitrogen. In consequence, the addition of further amounts of nitrogen as Sulphate of Ammonia, have not had the same large effects on the yield as were produced at the black soil centre. The first 40 lb. nitrogen increased the yield of the no-nitrogen plot by 1.8 tons cane per acre; the second increment of 40 lb. nitrogen increased the yield by a further 1.0 ton cane, whilst the third increment of 40 lb. nitrogen gave no further increase in the yield.

The maximum yield of 34.9 tons cane per acre obtained with 120 lb. potash and 120 lb. nitrogen is 6—10 tons below the yield which might be expected at this centre with this manuring under favourable climatic conditions.

The nitrogen plots show a slight increase in the per cent. sucrose in juice over the no-nitrogen plots, but these increases cannot be considered as significant, It is quite certain, however, that the increasing doses of nitrogen have had no depressing effect on the per cent. sucrose in the juice which has, so far, been invariably obtained with ratoon cane.

EFFECTS OF DIFFERENT TIMES OF APPLICATION OF NITROGEN AS SULPHATE OF AMMONIA.

As already noted, the nitrogen was applied in three different ways, viz., (a) 15 lb. nitrogen in January and the remainder in July; (b) all the nitrogen in July as one application and (c) half the nitrogen in July and half in September. The yield results in terms of tons of cane per acre and per cent. sucrose in juice are set out for the two centres in Tables IV and V.

TABLE IV.

EFFECT OF DIFFERENT TIMES OF APPLICATION OF NITROGEN ON YIELD AND PER CENT. SUCROSE IN JUICE.

BLACK SOIL CENTRE.

Treatment (lb. N per acre)	January and July		July		July and September	
	Tons Cane (mean of 5)	Per cent. Sucrose in juice (mean of 5)	Tons Cane (mean of 5)	Per cent. Sucrose in juice (mean of 5)	Tons Cane (mean of 5)	Per cent. Sucrose in juice (mean of 5)
40	28.9	19.17	27.2	19.21	24.4	19.16
80	34.7	19.52	34.7	19.35	30.6	19.09
120	38.1	19.47	39.4	19.52	34.9	19.13
Mean of 15 Plots	33.9	19.39	33.4	19.36	30.0	19.13

Statistical Analysis.

A difference between the means of 15 plots of 2.8 tons cane or 0.20 per cent. sucrose in juice, has a 20:1 chance of being due to treatment.

TABLE V.

RED SOIL–CENTRE.

Treatment (lbs. N. per acre.)	January and July.		July.		July and September.	
	Tons Cane (mean of 5.)	Per cent. Sucrose in juice (mean of 5)	Tons Cane (mean of 5.)	Per cent. Sucrose in juice (mean of 5.)	Tons Cane (mean of 5)	Per cent. Sucrose in juice (mean of 5.)
40	34·3	20·80	33·6	20·58	33·0	20·61
80	34·1	20·66	34·1	20·46	36·6	20·17
120	33·2	20·41	36·6	20·40	35·0	20·63
Mean of 15 Plots.	33·9	20·62	34·8	20·48	35·1	20·47

Statistical Analysis.

A difference between mean yields of 15 plots of 1.8 tons cane or 0.33 per cent. sucrose in juice, has a 20:1 chance of being due to treatment.

CONCLUSIONS.

BLACK SOIL CENTRE.

A consideration of the figures given in Table IV, shows that there was no effect on the yield of cane or per cent. sucrose in juice whether the nitrogen was applied all in July or whether a small part was given in January in the "Early Cane Manure." There is, however, a distinct drop in yield, averaging about 3½ tons of cane per acre, when the application of nitrogen was made half in July and half in September. It is evident that, under the growth conditions existing at this centre in 1933, the plant cane was unable to utilise all of the September application of nitrogen.

It will be further noted that the per cent. sucrose in juice of the cane from the July—September plots is significantly lower than that in the juice of the cane from the other plots. It follows that the cane from the plots on which the nitrogen had been applied in July and September was not as mature at the time of reaping as the cane from the other plots. This supports the suggestion already made that the cane had not utilised all of the September application of nitrogen at the time of reaping.

RED SOIL CENTRE.

At the red soil centre, the effects on the yield of additions of nitrogen as sulphate of ammonia were small and there are no significant differences in the yield of cane from the plots which received their nitrogen at different times. The effect on the per cent. sucrose in the juice of applying the nitrogen at different times is also entirely negative.

SECTION II.

THE EFFECT OF VARYING COMBINATIONS OF POTASH AND NITROGEN ON THE YIELD OF RATOONS. (1933–34).

EXPERIMENT 1.

This trial was a continuation of the trial on second ratoons, the results of which were recorded and discussed in Vol. II. (1933) No 4, p.12 of the Barbados Agricultural Journal. The canes reaped in the 1934 grinding season were third ratoons or fourth crop canes and the plots had been treated in exactly the same manner as in the previous year. (See Table VI.)

A representative sample of cane weighing approximately 100 lb. was selected for each different treatment from each block for analysis. Only one sample of cane for each treatment was subjected to a complete analysis, but the four block samples of each treatment were analysed separately in respect of sucrose in the juice.

RAINFALL.

The rainfall during the growing season April 1933—March 1934 for this centre was 89.66 inches. The average rainfall for the same months for the years 1890—1929 was 75.15 inches for the area representative of this centre.

The distribution of the rainfall compared with the average is shown in Fig. III. It will be noted that the rainfall from July to November was greatly in excess of the average.

The yields of cane and the per cent. sucrose in juice for the years 1932—33 and 1933—34, together with the manurial treatment, are set out in Table VI.

TABLE VI.

Plot No.	Treatment per acre		1932—33		1933—34	
	lb. Nitrogen as Sulphate of Ammonia	lb. Potash as Muriate of Potash	Tons Cane per Acre	Per cent Sucrose in Juice	Tons Cane per acre	Per cent Sucrose in Juice
			(Means of 4)		(Means of 4)	
1	0	0	36.4	19.83	19.1	21.29
2	40	0	38.1	19.56	19.4	21.18
3	80	0	38.4	19.29	21.3	20.08
4	120	0	40.4	19.30	21.6	19.71
5	0	40	35.3	19.83	17.6	21.00
6	40	40	36.3	19.47	20.0	21.49
7	80	40	36.5	19.43	25.2	20.45
8	120	40	37.5	19.18	23.0	19.92
9	0	80	36.2	19.61	20.7	21.48
10	40	80	37.2	19.58	17.9	21.49
11	80	80	37.7	19.14	20.5	20.87
12	120	80	38.8	19.78	23.4	20.42
13	0	120	34.3	20.01	18.2	21.39
14	40	120	36.4	19.90	19.2	21.54
15	80	120	38.7	19.91	21.2	21.15
16	120	120	38.3	19.12	22.8	20.45
	Mean of 16 Plots.		37.3	19.56	20.7	20.87

Statistical Analysis.

(a) A difference between the mean yields of 4 plots of 4.6 tons cane per acre for the 1932—33 results and 3.6 tons cane for the 1933—34 results has a 20:1 chance of being due to treatment.

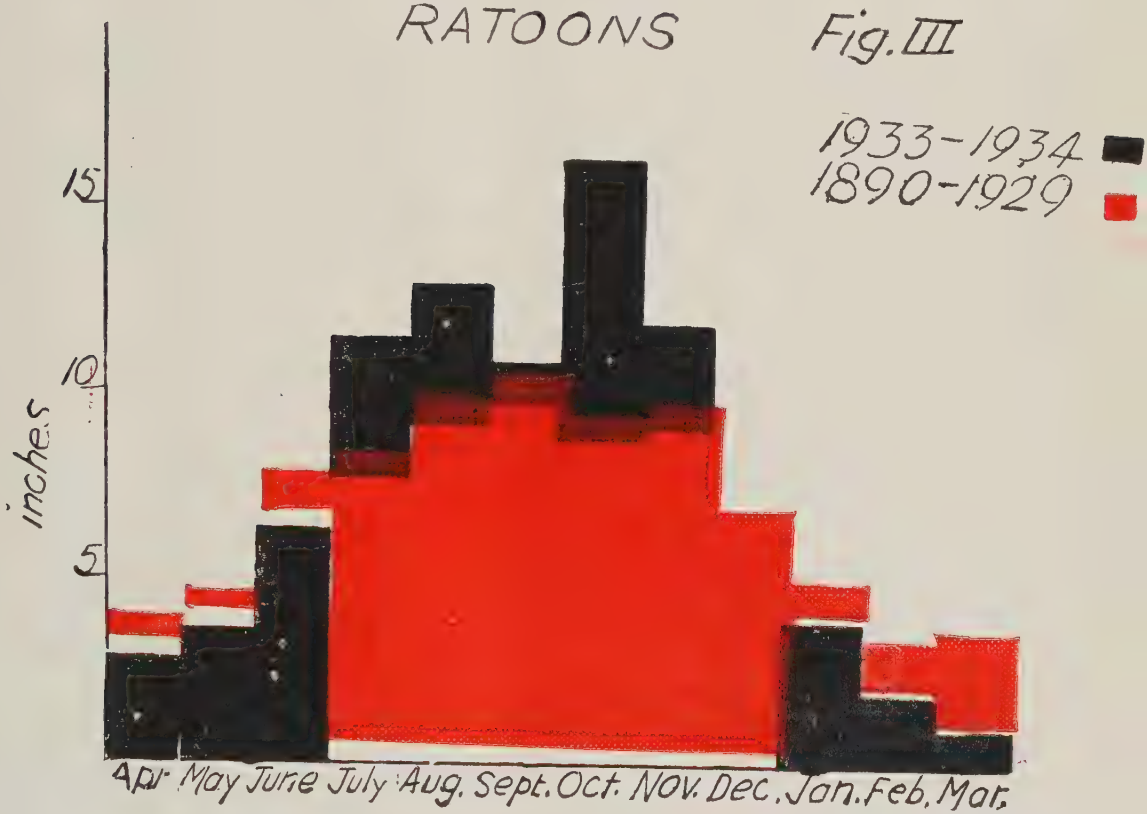
(b) A difference between the mean per cent. sucrose in the juice of 4 plots of 0.44 per cent. has a 20:1 chance of being due to treatment.

DISTRIBUTION OF RAINFALL.

Red Soil Centre

RATOONS

Fig. III



If the effects on the yield of the different doses of nitrogen or potash are considered separately and the effect, if any, of the other constituent is ignored, it is possible to consider the differences between the means of sixteen plots for each addition of nitrogen or potash and hence add to the precision of the experiment.

The yield of cane and per cent. sucrose in juice results for the year 1933—34 are treated in this way in Table VII and VIII.

TABLE VII.

EFFECT OF VARYING AMOUNTS OF NITROGEN ON YIELD AND PER CENT. SUCROSE IN THE JUICE OF THIRD RATOONS (1933–34).

Treatment per acre		Yield (Tons Cane)	Difference between means of 4 plots	Per cent Sucrose in Juice	Difference between means of 4 plots
lb. Nitrogen (N)	lb. Potash (K_2O)				
EFFECT OF 40lb. NITROGEN					
0	0	19.1		21.29	
			+0.3		—0.11
40	0	19.4		21.18	
0	40	17.6		21.00	
			+2.4		—0.49
40	40	20.0		21.49	
0	80	20.7		21.48	
			—2.8		+0.01
40	80	17.9		21.49	
0	120	18.2		21.39	
			+1.0		+0.15
40	120	19.2		21.54	
Difference between means of 16 plots			+0.2		—0.11

TABLE VII.—(*Continued*).

Treatment per acre		Yield (Tons Cane)	Difference between means of 4 plots.	Per cent Sucrose in Juice.	Difference between means of 4 plots.
lb. Nitrogen N.	lb. Potash K_2O.				
EFFECT OF 80lb. NITROGEN.					
0	0	19.1		21.29	
			+2.2		—1.21
80	0	21.3		20.08	
0	40	17.6		21.00	
			+7.6		—0.55
80	40	25.2		20.45	
0	80	20.7		21.48	
			—0.2		—0.61
80	80	20.5		20.87	
0	120	18.2		21.39	
			+3.0		—0.24
80	120	21.2		21.15	
Diff. between means of 16 plots			+3.1		—0.65
EFFECT OF 120lb. NITROGEN.					
0	0	19.1		21.29	
			+2.5		—1.58
120	0	21.6		19.71	
0	40	17.6		21.00	
			+5.4		—1.08
120	40	23.0		19.92	
0	80	20.7		21.48	
			+2.7		—1.06
120	80	23.4		20.42	
0	120	18.2		21.39	
			+4.6		—0.94
120	120	22.8		20.45	
Diff. between means of 16 plots			+3.8		—1.17

TABLE VIII.

EFFECT OF VARYING AMOUNTS OF POTASH ON THE YIELD AND PER CENT. SUCROSE IN JUICE OF THIRD RATOONS. (1933–34).

Treatment per acre.		Yield (Tons Cane)	Difference between means of 4 plots.	Per cent. Sucrose in juice.	Difference between means of 4 plots.
lb. Nitrogen N.	lb. Potash. K_2O.				
EFFECT OF 40 lb. POTASH.					
0	0	19·1	−1·5	21·29	−0·29
0	40	17·6		21·00	
40	0	19·4	+0·6	21·18	+0·31
40	40	20·0		21·49	
80	0	21.3	+3·9	20·08	+0·37
80	40	25·2		20·45	
120	0	21·6	+1·4	19·71	+0·21
120	40	23·0		19·92	
Difference between means of 16 plots			+1·1		+0 15
EFFECT OF 80 lb. POTASH.					
0	0	19·1	+1·6	21·29	+0·19
0	80	20·7		21·48	
40	0	19·4	−1·5	21·18	+0·31
40	80	17·9		21·49	
80	0	21·3	− 0·8	20·08	+0·79
80	80	20·5		20·87	
120	0	21·6	+1·8	19·71	+0·71
120	80	23·4		20·42	
Difference between means of 16 plots			+0·3		+0·50

TABLE VIII.—(*Continued*).

Treatment per acre.		Yield (Tons Cane.)	Difference between means of 4 plots.	Per cent. Sucrose in juice.	Difference between means of 4 plots.
lb. Nitrogen N.	lb. Potash K_2O.				
EFFECT OF 120 lb. POTASH.					
0	0	19·1		21·29	
			−0·9		+0·10
0	120	18·2		21·39	
40	0	19·4		21·18	
			−0·2		+0·36
40	120	19·2		21·54	
80	0	21·3		20·08	
			−0·1		+1·07
80	120	21·2		21·15	
120	0	21·6		19·71	
			+1·2		+0·74
120	120	22·8		20·45	
Difference between means of 16 plots			0·0		+0 57

The results recorded in Tables VII and VIII, together with the results for the 1932—33 crop are summarised in Tables IX and X.

TABLE IX.

EFFECT OF VARYING DOSES OF NITROGEN ON YIELD AND PER CENT. SUCROSE IN JUICE.

Treatment per acre.	Diff. from No-Nitrogen plots. Means of 16.			
	1932—33.		1933—34.	
	Yield (Tons per acre.)	Per cent Sucrose in Juice.	Yield (Tons per acre.)	Per cent. Sucrose in Juice.
40 lb. Nitrogen ...	+1·6	−0·19	+0·2	−0·11
80 lb. Nitrogen ...	+2·3	−0·38	+3·1	−0·65
120 lb. Nitrogen ...	+3·2	−0·63	+3·8	−1·17

TABLE X.

EFFECT OF VARYING DOSES OF POTASH ON YIELD AND PER CENT. SUCROSE IN JUICE.

Treatment per acre.	Diff. from No-Potash plots. (Means of 16.)			
	1932—33.		1933—34	
	Yield (Tons per acre.)	Per cent. Sucrose in Juice	Yield (Tons per acre)	Per cent. Sucrose in Juice.
40 lb. Potash ...	−1·9	−0·02	+1·1	+0·15
80 lb. Potash ...	−0·7	−0·12	+0·4	+0·50
120 lb. Potash ...	−1·4	+0·24	0·0	+0·57

Statistical Analysis of Tables VII to X.

A difference between the means of 16 plots of 1.8 tons cane or 0.22% sucrose in juice has a 20:1 chance of being due to treatment.

CONCLUSIONS.

1. YIELD OF CANES.

The yield results for the different treatments of the third ratoons (1933—34 crop) are very similar to the results obtained on the second ratoons in the previous year.

The increasing amounts of nitrogen have had similar increasing effects on the yield. The potash dressings, on the other hand, have had no significant effect in increasing the tonnage of cane. It can therefore be concluded that the soil of these plots was sufficiently rich in potash to grow two crops without potash manuring. These ratoons will be continued for another year and the plots will again be manured in the same way. It will be of interest to see the effect of potash on the fourth ratoon crop.

The average yield of the second ratoons over the plots was 37.3 tons whilst the average yield of the third ratoons was only 20.7 tons per acre. Under similar climatic conditions to which the 1932—33 crop was grown, the third ratoons would have averaged at least 30 tons of cane per acre. The increased yield of cane due to the nitrogenous manuring of third ratoons represent a much bigger percentage increase when expressed on the mean yield. It is possible that under more favourable climatic conditions, the increasing applications of Sulphate of Ammonia would have resulted in bigger tonnage differences.

2. PER CENT. SUCROSE IN JUICE.

The mean percentage sucrose in the juice for the 1932—33 crop of second ratoons was 19.56% whilst for the 1933—34 crop of third ratoons it was 20.87%. This high per cent. of sucrose in the juice for the 1934 crop was general throughout the island and was the direct result of the climatic conditions during the season which favoured the production of a mature cane at harvest.

The effects of the various nitrogenous dressings on the sucrose in the juice are very striking. The first 40 lb. nitrogen, as sulphate of ammonia, has had little effect; but the 80 lb. dressing and especially the 120 lb. dressing of nitrogen have had a very considerable depressing effect on the per cent. sucrose in the juice.

The gross effect of the potash dressings is seen to have the reverse effect on the sucrose in the juice. The increasing potash dressings have increased the sucrose in the juice, although these increases are less than the decreases brought about by the nitrogenous manuring.

The interactions of the nitrogenous and potash manurings on the sucrose in the juice are best seen in diagrammatic form and, in Fig. IV, the effects of different amounts of potash are shown for the four levels of nitrogenous manuring.

It will be noted that with the 80 lb. and 120 lb. dressings of nitrogen, all the three potash dressings increase the per cent. sucrose in the juice and the increase is greatest with the heaviest potash manuring. This result is similar to the conclusion reached last year in the manuring of these canes as second ratoons.

EXPERIMENT II.

This trial was laid out at the same red soil centre as Experiment 1, on second ratoons and the lay out was the same as before.

The plantation manuring of these canes as plant canes and first ratoons per acre had been as follows:—

Plant Canes. (1930—1931) per acre.

Before planting	:	3 squares Pen Manure. (approximately 25 tons).
In January	:	2 cwt. Muriate of Potash and 1 cwt. Sulphate of Ammonia.
In June	:	320 lb. Sulphate of Ammonia.

First Ratoons. (1932—33) per acre.

In May	:	1 cwt. Muriate of Potash and 1 cwt. Sulphate of Ammonia.
In June	:	2 cwt. Sulphate of Ammonia.

Yields of Second Ratoons. (1933—34).

The yields and the per cent. sucrose in juice together with particulars of the manurial treatment are set out in Table XI.

Effect of NITROGEN and POTASH
on the per cent SUCROSE in Juice.

Red Soil centre 1933-1934. Third RATOONS.

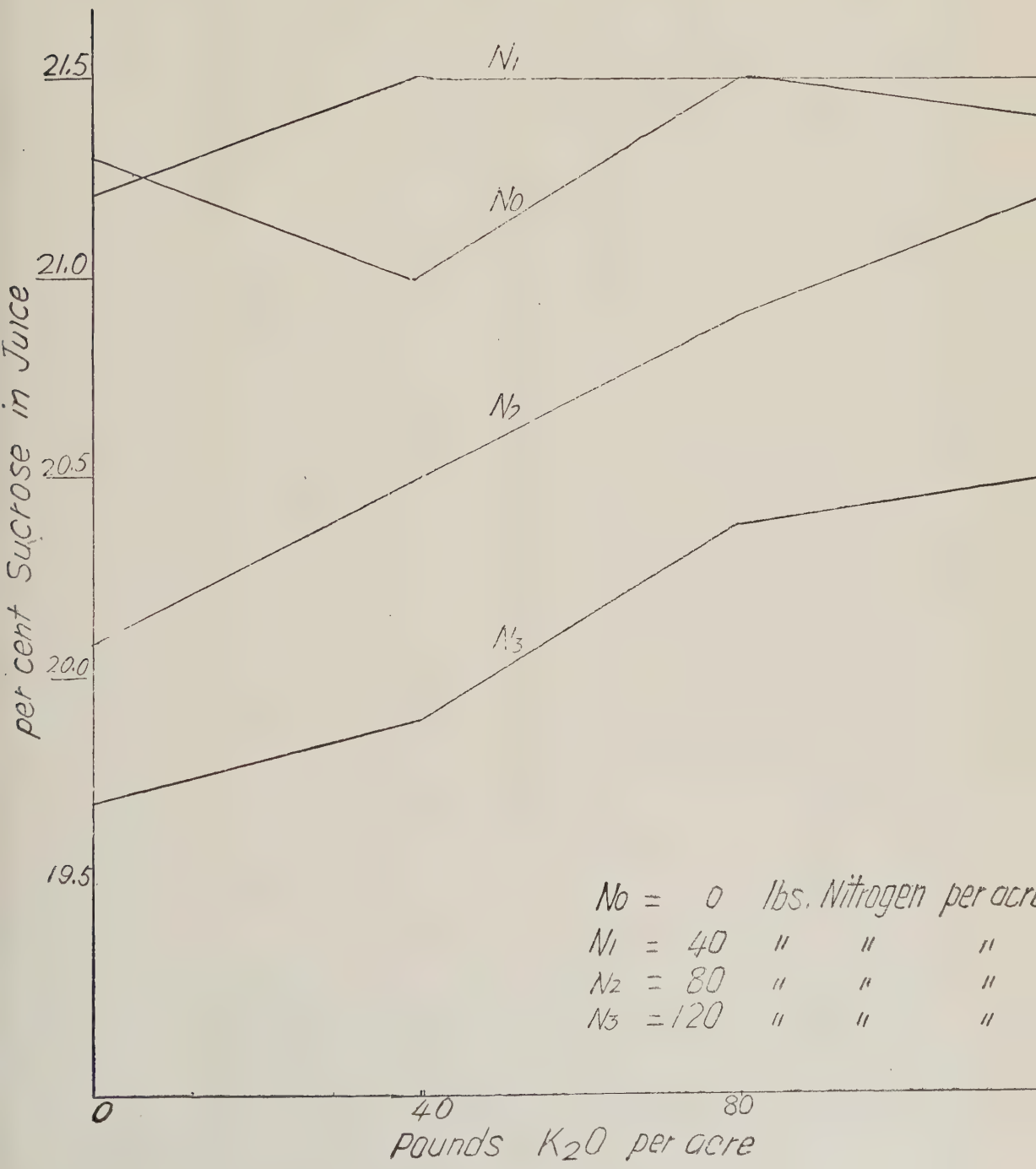


Fig IV.

RAINFALL.

The rainfall data for the growing period 1933—34 at this centre have already been recorded earlier in this section. (See Fig. III).

TABLE XI.

Plot No.	Treatment per Acre. lb. Nitrogen as Sulphate of Amonia.	lb. Potash as Muriate of Potash.	Tons Cane per Acre. (Means of 4)	Per cent. Sucrose in Juice.
1	0	0	22.4	19.66
2	40	0	24.3	19.70
3	80	0	28.4	19.23
4	120	0	30.0	19.12
5	0	40	24.5	19.33
6	40	40	25.1	19.68
7	80	40	29.3	19.61
8	120	40	29.0	18.67
9	0	80	23.0	19.64
10	40	80	25.6	20.00
11	80	80	26.5	19.19
12	120	80	31.8	18.96
13	0	120	23.0	19.69
14	40	120	23.5	20.01
15	80	120	28.2	19.38
16	120	120	30.9	19.30
		Mean Yield	26.6	

Statistical Analysis.

A difference between the means of 4 plots of 3.9 tons cane or of 0.6% sucrose in the juice, has a 20:1 chance of being due to treatment.

The effects of the applications of nitrogen and potash have been examined more exactly in Tables XII and XIII, and the differences between the means of 16 plots are given in Tables XIV and XV.

TABLE XII.

THE EFFECT OF VARYING AMOUNTS OF NITROGEN ON YIELD AND PER CENT. SUCROSE IN THE JUICE OF SECOND RATOONS. (1933–34).

Treatment per acre.		Yield (Tons Cane)	Difference between means of 4 plots.	Per cent. Sucrose in juice.	Difference between means of 4 plots.
lb. Nitrogen N	lb. Potash K_2O				
EFFECT OF 40 lb. NITROGEN.					
0	0	22.4		19.66	
			+1.9		+0.04
40	0	24.3		19.70	
0	40	24.5		19.33	
			+0.6		+0.35
40	40	25.1		19.68	
0	80	23.0		19.64	
			+2.6		+0.36
40	80	25.6		20.00	
0	120	23.0		19.69	
			+0.5		+0.32
40	120	23.5		20.01	
Difference between means of 16 plots			+1.4		+0.27
EFFECT OF 80 lb. NITROGEN.					
0	0	22.4		19.66	
			+6.0		−0.43
80	0	28.4		19.23	
0	40	24.5		19.33	
			+4.8		+0.28
80	40	29.3		19.61	
0	80	23.0		19.64	
			+3.5		−0.45
80	80	26.5		19.19	
0	120	23.0		19.69	
			+5.2		−0.31
80	120	28.2		19.38	
Difference between means of 16 plots.			+4.9		−0.23

TABLE XII.—(*Continued*).

Treatment per acre.		Yield (Tons Cane)	Difference between means of 4 plots	Per cent Sucrose in Juice	Difference between means of 4 plots.
lb Nitrogen N	lb Potash K_2O				
EFFECT OF 120 lb. NITROGEN.					
0	0	22.4	+7.6	19.66	−0.54
120	0	30.0		19.12	
0	40	24.5	+4.5	19.33	−0.66
120	40	29.0		18.67	
0	80	23.0	+8.8	19.64	−0.68
120	80	31.8		18·96	
0	120	23.0	+7.9	19,69	−0.39
120	120	30.9		19.30	
Difference between means of 16 plots			+7.2		−0.57

TABLE XIII.

THE EFFECT OF VARYING AMOUNTS OF POTASH ON YIELD AND PER CENT. SUCROSE IN THE JUICE OF SECOND RATOONS. (1933–34).

Treatment per acre.		Yield (Tons Cane.)	Difference between means of 4 plots.	Per cent. Sucrose in Juice.	Difference between means of 4 plots.
lb. Nitrogen N.	lb. Potash K_2O				
EFFECT OF 40 lb. POTASH.					
0	0	22·4		19·66	
			+2·1		−0·33
0	40	24·5		19·33	
40	0	24·3		19·70	
			+0·8		−0·02
40	40	25·1		19·68	
80	0	28·4		19·23	
			+0·9		+0·38
80	40	29·3		19·61	
120	0	30·0		19·12	
			−1·0		−0·45
120	40	29·0		18·67	
Difference between means of 16 plots			+0·7		−0·10
EFFECT OF 80 lb. POTASH.					
0	0	22·4		19·66	
			+0·6		−0·02
0	80	23·0		19·64	
40	0	24.3		19·70	
			+1·3		+0·30
40	80	25·6		20·00	
80	0	28·4		19·23	
			−1·9		−0·04
80	80	26·5		19·19	
120	0	30·0		19·12	
			+1·8		−0·16
120	80	31·8		18·96	
Difference between means of 16 plots			+0·5		+0·02

TABLE XIII.—(*Continued*).

Treatment per acre.		Yield (Tons Cane.)	Difference between means of 4 plots.	Per cent. Sucrose in Juice.	Difference between means of 4 plots.
lb. Nitrogen N.	lb Potash K_2O				
EFFECT OF 120 lb. POTASH.					
0	0	22·4	} +0·6	19·66	} +0·03
0	120	23·0		19·69	
40	0	24·3	} −0·8	19·70	} +0·31
40	120	23·5		20·01	
80	0	28·4	} −0·2	19·23	} +0·15
80	120	28·2		19·38	
120	0	30·0	} +0·9	19·12	} +0·18
120	120	30·9		19·30	
Difference between means of 16 plots			+0·1		+0·17

TABLE XIV.

EFFECT OF VARYING DOSES OF NITROGEN ON YIELD AND PER CENT SUCROSE IN JUICE.

Treatment per acre.	Difference from No-Nitrogen Plots (Means of 16).	
	Yield (Tons per acre).	Per cent. Sucrose in Juice.
40 lb. Nitrogen	+1·4	+0·27
80 lb. Nitrogen	+4·9	−0·23
120 lb Nitrogen	+7·2	−0·57

TABLE XV.

EFFECT OF VARYING DOSES OF POTASH ON YIELD AND PER CENT. SUCROSE IN JUICE.

Treatment per acre.	Difference from No-Potash Plots. (Means of 16).	
	Yield (Tons per acre).	Per cent. Sucrose in Juice.
40 lb. Potash	+0·7	−0·10
80 lb. Potash	+0·5	+0·02
120 lb. Potash	+0·1	+0·17

Statistical Analysis of Tables XII—XV.

A difference between the means of 16 plots of 2.0 tons cane or of 0.35% sucrose in the juice, has a 20:1 chance of being due to treatment.

It should perhaps be noted that the mean yield of these second ratoons was 26.6 tons cane per acre, as compared with a mean yield of 37.3 tons cane for second ratoons manured in the same way and grown on the same plantation in the previous season. The yield difference must be largely due to the climatic factors associated with the excessive rainfall which fell between July and November.

CONCLUSIONS.

1. YIELD OF CANES.

The increasing doses of nitrogen have had a greater effect on the yield of these second ratoons than was recorded in the previous experiment reaped in 1933. The first 40 lb. nitrogen as Sulphate of Ammonia, has increased the no-nitrogen plots at the rate of 1.4 tons per acre; the second 40 lb. by 4.9 tons and the third 40 lb. by 7.2 tons of cane per acre.

The various dressings of potash have had no effect on the yield of these ratoons. This supports the previous finding that the soil on this particular estate must have good reserves of potash.

2 PER CENT. SUCROSE IN JUICE.

As recorded in previous trials on ratoons, the 80 lb. and 120 lb. dressings of nitrogen, as Sulphate of Ammonia, have had a depressing effect on the per cent. sucrose in the juice.

As in the previous trials, this depressing effect of nitrogenous manuring has been partially offset by potash manuring.

SECTION III.

THE EFFECT OF PHOSPHORIC ACID ON THE YIELD OF PLANT CANES (1932—34).

Previous manurial trials have shown that the sugar cane does not respond to phosphatic manuring on the coral limestone soils of Barbados. No similar trial has yet been carried out on a "Scotland" soil and this experiment was planned to determine the effect of phosphatic manuring on the yield of plant cane grown on such a soil which, on analysis, gave no water soluble phosphoric acid.

Since the "Scotland" soils are very heterogeneous in character, it should be recorded that this field was at Mount Wilton plantation and the soil can be described as a heavy clay. Certain laboratory determinations carried out on samples of the soil and subsoil are given in Table XVI.

TABLE XVI.

	Index of Texture.	Loss on Ignition. %	Total Nitrogen. %	Calcium Carbonate. %	pH	Water Soluble P_2O_5	Exchangeable K_2O
						p.p.m.	
Soil	40.8	10.31	0.155	0.63	7.2	0.00	0.0151
Subsoil	41.5	8.88	0.121	0.11	7.2	0.00	0.0111

PLAN.

The trial was laid out after the ABBA method of Student, with ten replicates for the phosphate and no-phosphate plots respectively.

The size of each plot was 3 x 20 cane holes and the inside 20 holes of cane were cut and weighed in the estimation of yield.

A representative sample of cane weighing approximately 100 lb. was selected from each plot for analysis.

The A plots received no phosphate whilst the B plots received Superphosphate at the rate of 450 lb. per acre.

GENERAL MANURING.

With the exception of the phosphate application, the plots were treated in exactly the same way, viz.

In January, a mixture of Muriate of Potash and Sulphate of Ammonia was applied, which supplied the equivalent of 103 lb. potash and 15 lb. nitrogen per acre.

In July, a dressing of Sulphate of Ammonia, was given which supplied the equivalent of 70 lb. nitrogen per acre.

RAINFALL.

The amount and distribution of the rainfall was very similar to the figures already given for the red soil centre in Section I (See Fig. I.) It will be noted that the rainfall was well above the average for December and January and for the following months of July to November.

TABLE XVII.

Plot	Yield Tons per Acre.	Per cent. Sucrose in Juice.	Purity of Juice.	Plot	Yield Tons per Acre.	Per cent. Sucrose in Juice.	Purity of Juice.
A 1	37.34	16.61	90.9	B. 1	39·17	16·07	89·1
A 2	43.21	17.30	90.6	B. 2	38·08	16·07	88·7
A 3	39.67	17.04	90.2	B. 3	45·08	16·86	89·6
A 4	44.38	17.14	90.7	B. 4	40·45	16·07	89·1
A 5	36.56	16.60	90.4	B. 5	33·76	16·24	89·2
A 6	41.62	16.15	88.3	B. 6	44·73	16·78	90·0
A 7	35.79	17.47	90.4	B. 7	42·21	16·60	89·7
A 8	36.51	15.71	88.4	B. 8	40·11	17·12	90·2
A 9	35.54	15.62	88.4	B. 9	34·10	16·07	88·7
A 10	39.70	16.34	89.8	B.10	34·72	15·72	88·9
Means of 10	39.03	16.60	89.81		39·24	16·34	89·32

Statistical Analysis.

A difference between the means of ten of 2.6 tons of cane or 0.50% sucrose in juice, has a 20:1 chance of being due to treatment.

CONCLUSIONS.

Reference to the mean figures given in Table XVII shows quite clearly that the addition of Superphosphate to the B plots has had no significant effect either on the yield of cane or on the per cent. sucrose in the juice.

If this result is of general application to all "Scotland" soils, it is evident that the phosphatic manuring of sugar cane on such soils is not an economic proposition.

THE CONTROL OF DIATRAEA SACCHARALIS IN SUGAR CANE IN BARBADOS, BY FREQUENT LIBERATION OF MASS REARED TRICHOGRAMMA.

A REVIEW OF DATA OBTAINED FROM 1929–1934.

By R. W. E. TUCKER, M.A., B.Ed.

INTRODUCTION.

The question of the control of *D. saccharalis* in cane by means of mass reared *T. minutum*, liberated during a selected portion of each year, resolves itself into two main discussions.

I. What is the situation in canefields under normal conditions, with a natural balance between *Diatraea* and *Trichogramma* and other mortality factors?

II. What are the results of annual large scale liberations of artificially reared *Trichogramma* on the above normal conditions?

Dealing with I, it is found that information is required on:—

(a) the extent of natural parasitism of *Diatraea* eggs by *Trichogramma*;

(b) the egg deposition rate;

(c) the average numbers of eggs deposited per unit of one acre of canes, week by week, for as many months as possible;

(d) the conditions affecting egg deposition and mortality.

(e) the real mortality of *Diatraea* eggs due to parasitism predators and other causes;

(f) the rate of *Diatraea* larval mortality;

(g) the *total real mortality* of all the mortality factors which operate on the *Diatraea* complex.

Dealing with II, it is necessary to determine,

(a) whether colonisation of mass reared *Trichogramma* raises the normal rate of parasitism of *Diatraea* eggs to a determinable extent;

(b) whether earlier or increased colonisations of parasites cause earlier and increased rises in field parasitism;

(c) whether increased egg parasitism results in a noticeable increase in the total real mortality of *Diatraea* population and therefore in a diminution of accumulated damage caused by borers in cane, diminution in damage being measured by:—

(1) decreased joint infestation;

(2) decreased field loss due to breaking and rotting of canes and killing of young canes;

(3) increase in juice purity due to fewer bored canes;

(4) increased output of sugar per acre.

(d) finally, whether progressive increase of total real mortality and diminution of accumulated damage to the cane crop results in progressive and permanent lowering of the pest population level from its status prior to *Trichogramma* colonisation.

It is obvious from the foregoing series of points, that very considerable data are necessary to make clear the process of any method of control over *Diatraea,* and to substantiate any claims made concerning reduction in infestation of this pest in sugar cane.

To obtain sufficient data on any one of these points is enough to keep one worker busy for the greater part of a year, or series of years. No one worker can obtain reliable data over the entire series given above.

Considerable data have, however, been collected over a period of six years by means of personal field work; also by members of the staff of the Department of Science and Agriculture of Barbados, so far as they could be spared for such work. The results of experiments laid out by the Geneticist in the form of randomised blocks, to test different varieties of cane, have also been used to yield entomological data, and in some instances the layout of an experiment has been suitable to entomological work as well as for the purpose for which it was originally intended.

The results of this work are sufficiently extensive and coherent to justify their publication in the following pages, and to warrant the conclusion drawn in this, and in foregoing publications as to the value of *Tichogramma* control in Barbados. No claim is made, however, that the work is complete, or that the figures are final or absolutely exact; the difficulty of obtaining truly exact figures in biological field work is known, and needs no apology.

The writer does, however, state that the figures given are impartial, in that the major portion of the data has been obtained by independent workers and all data obtained are subjected to periodic checking in the field or experimental plots where it is being obtained.

Some of the results given may be regarded as definite evidence, and as proof of the series of points set out above; others may be regarded as indications only, as in the case of the level of parasitism determined in the field year by year. Both proofs and indications, however, all point to the same direction and lead to the conclusion that mass reared *Trichogramma* has effected a reduction in infestation of *D saccharalis* in sugar cane in Barbados.

I. THE SITUATION IN CANE FIELDS UNDER NATURAL CONDITIONS.

(a) NATURAL PARASITISM BY TRICHOGRAMMA.

The first point of the series given above is the extent of natural parasitism by *Trichogramma,* determined week by week, for as many months as possible each year. The necessity for the information was realised at the very outset of control work on *D saccharalis* in Barbados, and an attempt was made to obtain the required data, but due to the lack of trained workers, and as less than a year elapsed between the writer's arrival in Barbados, and the first mass liberation of parasites, the determination of this point was precluded.

In the absence, therefore, of adequate observation on the natural parasitism by *Trichogramma* in Barbados, prior to work carried out by the writer, it can only be said that the data obtained by subsequent field observations show that average natural parasitism by *Trichogramma* is negligible until somewhere in April or even in May. It is necessary to emphasise *average* parasitism because it is perfectly possible to find every range from no *Trichogramma* or no *Diatraea* eggs in some fields, up to large numbers of eggs and up to large numbers of *Trichogramma* in others; and therefore a large number of fields must be examined and averaged.

From May onwards in Barbados, normal egg deposition by *Diatraea* rapidly increases, reaching a high level in August and September, and maintaining a fairly high level until the crop is reaped from February to May in the following year; a slight decrease in numbers usually occurs from December onwards. From June onwards normal parasitism by *Trichogramma* becomes more uniform, and the average figure of parasitism increases until by September or October it may reach between 50% to 90% with an average of around 60%. By then, under normal conditions, the most serious damage to canes has already been done, and the pest population level is already so high, that even an average natural parasitism of 60% *Diatraea* eggs still leaves sufficient larvae to hatch and to survive a natural mortality of from 50% to 70% at that period, to cause very noticeable damage to the softer upper growth of large canes and to penetrate mature cane stalks via the 'eyes.' The normal operation of *Trichogramma* is, therefore, most probably instrumental in preventing catastrophic infestation of *Diatraea*, but not sufficient to give a control which is economic.

Prior to the high natural parasitism from September or October onwards the average parasitism by *Trichogramma* from June to September does not normally exceed from 30% to 50%, and prior to June may fluctuate from 0% to an average of 20% to 30%.

It is also well-known that the rate of normal parasitism by any parasite depends largely on the numbers of the host present; rising in the case of *Trichogramma,* when eggs are abundant, and falling when eggs are scarce.

Climatic conditions which affect *Diatraea* egg deposition are also likely to affect the efficiency of *Trichogramma,* though the nature of the relationship has not been determined, save that it has been found that drought and high winds diminish the extent of parasitism by *Trichogramma.* It is most probable, that extremes of rain and wind or of heat and drought, will affect the smaller and more delicate parasite far more adversely that it does the host *Diatraea.*

(b) EXTENT OF EGG DEPOSITION BY DIATRAEA.

Proceeding now to point (b) in the first discussion, namely the egg deposition rate of *Diatraea* in the field, its regularity and uniformity, and the curve of annual average deposition, no information is available on this point prior to control work. Subsequent to control work, however, exact information on the point was obtained by careful experiment in 1933 and has been published in (11), and confirmed by subsequent experiments in 1934.

The results obtained are not claimed as representing, accurately, conditions in large fields of different varieties in different districts, but they serve at least as a reasonably reliable indication of actual conditions in 12 non-colonised plots after 5 years control work, and it is legitimate to consider that the conditions thus demonstrated bear a reasonable relation to normal conditions.

Further, from data obtained from large scale field collections of *Diatraea* eggs, it can be said that normally the curve of egg deposition rises steadily (sometimes sharply) to a peak in September and October and diminishes slowly from December onwards. From the experiment referred to above, it is also clear that despite the normal upward curve of total egg deposition as described, *Diatraea* egg deposition is most irregular, some stools or some canes of a field, at any one period, having numerous eggs deposited and others having few or none.

(c) NUMBER OF EGGS PER ACRE PRIOR TO CONTROL.

No data is available as to the number of *Diatraea* eggs deposited per acre week by week or month by month in Barbados prior to control work. The results obtained in the experiment detailed in (11) are probably influenced by *Trichogramma* colonisation in surrounding fields for that year, so that from May onwards, egg deposition in the uncolonised plots decreases instead of increasing. Nevertheless, up to May the experimental block carried an infestation equal to, if not slightly in excess of, that shown by dead heart counts to exist in other fields all over the Island; this was due, no doubt, to the experimental block being deliberately infested early in the year to ensure that an adequate borer population was present for examination and measurement during the experiment. The highest count of eggs per month obtained as detailed in (11) was 24,000; further the average error in the bi-weekly count of eggs was placed at 15%, which is considered to make the fullest allowance for a maximum error of 20% and a minimum error of 2%, found to exist in these counts. This would make the highest egg deposition around 27,000 per acre per month for the conditions and period of the year as stated. Figures obtained in 1934 (allowing for the effects of very low rainfall in this year) show that this number of eggs per acre is not likely to be exceeded to any great extent in Barbados under present conditions.

No direct comparisons are thus available between extent of *Diatraea* egg deposition before *Trichogramma* colonisation and during years of colonisation. The results obtained, however, show definite indications that large scale distributions of *Trichogramma* reduce the level of pest population and that the reduction increases each year that the distribution of parasites is increased. This is confirmed by the mathematical results given in "A further Contribution to the Analysis of Field Data on *Diatraea saccharalis*." (14)

(d) CONDITIONS AFFECTING EGG DEPOSITION BY DIATRAEA.

The conditions which affect egg deposition would need lengthy research in field and laboratory to yield tangible results. A certain amount of progress has been made as detailed in (12) in determining whether cane leaf surface and variety of cane influence egg deposition by *Diatraea*.

It has been proved in the case of other insects that temperature and humidity, wind and rain will influence the rate and extent of egg deposition directly: as well as indirectly through larval mortality; but so far very little information is available on the nature and extent of these factors, in so far as they affect *Diatraea* in Barbados. Some preliminary work on these lines has been carried out and is given in Appendix I.

It is definite from these observations that there is a greater range of temperature inside a canefield compared with outside, and, of course, a very great reduction of wind velocity inside a canefield compared with outside. Also that humidity inside a canefield is greater than outside, and that humidity is highest and most constant throughout the night. Knowledge of the effect of these factors on fecundity and mortality factors of *Diatraea*, would not enable any control to be obtained over them, or use to be made of them, but the information would at least serve to interpret and possibly anticipate, the effect which yearly variations would have on the prevalence of and damage due to *Diatraea*, and to assess with a greater degree of certainty the real effect of any control measures against this pest.

(e), (f), (g). EGG MORTALITY AND LARVAL MORTALITY.

The final points (e), (f), and (g) in the first discussion, namely normal egg mortality, normal early larval mortality and final or total rate of larval mortality have been dealt with in (11), (13) and (14).

In the first paper quoted, bi-weekly determinations are recorded of parasitism by *Trichogramma* in twelve uncolonised plots of canes, each of 40 cane stools, and of egg mortality due to predators such as *Atomus* and *Psocid* larvae under conditions which obtained in 1933. As mentioned earlier on, these records are undoubtedly influenced by the fact that routine colonisations of *Trichogramma* were made in the surrounding countryside; nevertheless the figures obtained in these uncolonised plots are an indication of normal conditions, though most probably better than normal conditions were prior to *Trichogramma* liberations.

The monthly determinations of larval mortality which are given in detail in the above paper show that early larval mortality is not a sudden or instantaneous procedure, but that a large proportion of larvae leave definite records on the cane shoots and sometimes cause permanent damage before disappearing or dying; and the final or total rate of larval mortality varies month by month. High figures of over 90% total larval mortality are shown to occur in the early months of cane growth, but from May to June onwards, when cane shoots rapidly form an interlocking growth, larval mortality is much lower. With a lower, variable larval mortality rate, and with a diminishing power on the part of the cane stools to replace shoots which are killed, borer damage to the young and succulent cane growth becomes permanent and cumulative, and it is during this critical period of growth from May or June to September or October, that the main dam-

age to the crop is inflicted and the main control over *Diatraea* secured by mass colonisation of *Trichogramma.*

Some notes and observations on larval behaviour and early larval mortality are given in Appendix II.

The influence of the various mortality factors during egg, larval and adult stage on the total real mortality is fully discussed in (13).

Evidence is now available to show that the factors which combine to cause a natural or general early larval mortality are not constant, but that whilst high rates of larval mortality are prevalent during some periods of the year, it is equally certain that low rates of larval mortality preponderate during other periods of the year inclusive of the critical months of cane growth. This is a fact to be borne in mind.

The final query in this section, namely, what is the *total real mortality* value of all the different values of mortality factors operating in each *Diatraea* cycle, is dealt with in (14).

This, then, is the review of the situation in cane fields under normal conditions, as at present known, with *D. saccharalis* balanced against its natural mortality factors. The following section reviews the effect of annual large scale liberations of *T. minutum* on the above normal conditions, and gives comparisons between the natural or uncolonised conditions and conditions produced by colonisation of *Trichogramma.*

II. EFFECT OF PROGRESSIVELY INCREASED LIBERATIONS OF TRICHOGRAMMA.

(a) RECORDS OF INCREASED FIELD PARASITISM.

The first question that arises in the second portion of the discussion is whether colonisation of mass-reared *Trichogramma* raises the normal rate or level of egg parasitism to a determinable extent. The method adopted to determine this point has been detailed elsewhere [(10) p.87], and was found to be workable and reasonably reliable; a maximum of 20% and a minimum of 2% of egg masses missed were found to be the range of error in any of several checked counts in 1931, 1932, and 1933. This method can also be carried out bi-monthly in the same spot in a large number of estate fields for a period of several months of each year, or bi-monthly for the entire year in experimental plots, with no detriment to the fields or plots such as would be caused by repeatedly cutting off hundreds of cane leaves at random for laboratory examination.

Thus, over a period of five years in Barbados, considerable data have been accumulated, on field parasitism of *Diatraea* by *Trichogramma.*

The correct handling and interpretation of these data, however, is not an easy matter and may well be taken as an example of the difficulties which beset the statistical examination of field data, when biological and climatic factors enter in to add further complications to the field errors in sampling.

Thus, the material to be examined consists of a series of collections of eggs made from fields, irrespective of whether they had received artificial colonisation of *Trichogramma* or not. These collections are grouped into monthly units because as previously stated (11) the month is the most satisfactory period in which to obtain adequate samples, and during which, climatic and biological factors can be held to operate at a reasonably stable level. Also, records are not used beyond October, because in the first place, parasite liberations do not now go beyond October; and, in the second place, because experience has shown that field records from September to October onwards are obtained under trying conditions, which may make the chances of error too great. From the individual collections thus obtained, percentages of parasitism are worked out, but for monthly comparison, all collections are lumped together, and the percentage of eggs parasitised in the total is taken.

Unfortunately, the monthly quantitative collections fluctuated widely in the first two years, 1929 and 1930, owing to the assistance of a Field Officer during a portion only of 1929, causing collections to be from 15 to 25 times greater in months of normal heavy egg deposition and high parasitism, namely September, October and November, than in the earlier months of low parasitism; and in 1930 to the same cause (though to a less extent) together with the climatic vagaries of very low and irregular rainfall, causing fluctuations in the normal monthly cycle of egg deposition.

The ideal method, it would appear, is to sample the *entire* egg population by taking a sample from every field in the Island, at least twice every month, and taking the same time over collecting each sample. This, naturally, is impossible.

It remains then to ascertain the best method of using the data which have been collected, as described previously on a scale, and over a period of time, greater than has been attempted or has been practicable to the knowledge of the writer in any other *D. saccharalis* area.

Can the mass of data, accumulated over an eight-monthly period in each of five consecutive years, yield reliable information, and give some idea as to the value of the liberation of *Trichogramma* made in these years?

It must first be pointed out that reliable information does not necessarily mean exact information: it is impossible with present resources to obtain exact information on this complex biological problem. On the other hand, the reliability of field data is now universally measured by the degree of error as worked out by formulae evolved by statisticians. By this means it is possible to say whether the figures arrived at, have any meaning with reference to the point in support of which they are produced.

In this respect the biologist has more to contend with than many other compilers of field data.

Thus, in the present problem, the wide quantitative inequalities of sampling, due to three separate causes, have to be rectified, because to lump in two or three months of large quantitative samples, and high natural parasitism with five or four months of co-incident small quantitative samples and low natural parasitism, cannot give reliable information.

A standard which will level up all the quantitative samples for each month is therefore desired, and the figures or percentage parasitism obtained from such equal quantitative samples are then suitable for submission to statistical enquiry.

It was thought correct to make the standard sample one of one hundred eggs, averaged from the entire monthly samples. Thus the per cent. parasitism for any one month was held to give reliable information as to the *level* of parasitism at that period, irrespective of the fact that the monthly samples were very irregular in size.

This may be held to be satisfactory for comparing corresponding months of each year.

In order to compare the level of parasitism for a 6 month period of parasite liberation in each year, these equal samples were added up, and the percentage of eggs parasitised in the total was taken as giving reliable information as to average level or degree of parasitism for that portion of the year. This, of course, is equivalent to taking the mean of a series of percentages, but as each percentage has been based on a different quantitative sample, may be held as not giving the true percentage for the year. It has been pointed out that the true percentage is impossible of attainment and is, moreover, not obtainable from the data available. It is considered, however, that any objection to a monthly sample of one hundred eggs can be overcome by taking as the monthly sample a round number of eggs which is a fair average of the total number of monthly collections. The figure 8,000 fills this requirement.

Thus in every month it is held that around 8,000 *Diatraea* eggs are collected. If the actual figure for any month is less than that, then all collections made are increased in proportion: and if the monthly collection exceeds 8,000, then collections are reduced so that the totals for each month approximate 8,000. In all cases the collections are increased or decreased in the same proportion for that month. It cannot, of course, be expected that the exact figure of 8,000 will be reached each month, but in all cases, the final monthly figures can be made to approximate to 8,000 without disturbing the proportion of parasitised to unparasitised eggs originally collected.

In this manner, the quantitative differences are smoothed out and the monthly percentages of parasitism are comparable for the entire period of six months and can be held to give a reasonable indication of the average level, or degree of parasitism during the period of parasite liberation for each year. Further, both the monthly and annual figures can be submitted to statistical analysis to determine whether any increases in parasitism are due entirely to the operation of chance, or whether it is reasonable to conclude that the general upward tendency in parasitism is due to liberation of parasites despite the inequalities of the climatic and biological factors during the years under consideration.

The results of a collection of around 8,000 eggs each month, are given in Table I.*

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* In 1929 and 1930, and to some extent in 1931, parasite liberations were made principally in the Southern and Western areas of the Island and records of field parasitism were made mainly in these areas; from 1932 the whole Island received parasites in a more even manner.

TABLE I.

Month.	1929.			1930 **			1931.			1932.			1933.		
	Standard Collection.	Eggs Parasitised.	Per cent. Parasitism.	Standard Collection.	Eggs Parasitised.	Per cent. Parasitism.	Standard Collection.	Eggs Parasitised.	Per cent. Parasitism.	Standard Collection.	Eggs Parasitised.	Per cent. Parasitism.	Standard Collection.	Eggs Parasitised.	Per cent. Parasitism.
*April	7,920	0	0	—	0	—	7,936	462	5·8	7,995	727	9·1	7,993	1,303	16·3
May	8,166	1,743	21·3	7,924	3,198	40·3	7,935	3,642	45·9	7,912	3,825	48·3	8,044	5,065	62·9
June	7,812	4,476	57·0	8,042	1,742	21·6	8,013	3,891	48·5	8,001	3,987	49·8	8,479	5,699	67·2
July	7,575	2,080	27·4	8,015	3,632	45·3	8,334	5,598	67·1	7,784	5,297	68·0	7,995	5,824	72·8
August ...	7,979	4,927	61·7	7,925	5,168	65·2	8,345	6,316	75·6	8,031	6,769	84·2	8,260	5,782	70·0
September ...	8,440	6,166	73·0	8,193	6,348	77·4	8,079	6,844	84·7	8,388	7,557	90·0	8,073	7,380	91·4
October ...	7,920	6,901	87·1	8,188	6,867	83·8	7,768	7,138	91·8	7,991	7,564	94·5	7,984	7,286	91·2
Total Standard Collections May—Oct.	47,892	26,293	54·9	48,287	26,955	55·8	48. 474	33,449	69·0	48,107	34,999	72·7	48,835	37,036	75.8
Mean of Monthly Per cent. Parasitisms			54·6			55·6			68·9			72·5			75·9

** Year of drought.

* April records are not included in the summary of this Table, nor in Graph I, because the 1930 records do not show the number of eggs examined, thus spoiling the series. The April records for the other years are, however, included as illustrating the value of earlier and larger colonisations on field parasitism.

Attention must be called to the fact that observations made in 1934, a year of very low rainfall till nearly the middle of September, show that the effect of drought conditions is to lower the rate of parasitism recorded for *Trichogramma;* therefore, the level of parasitism shown for 1930 (an exceptionally dry year) is adversely affected, and shows very little increase over 1929, despite the increased liberation of parasites in 1930. Had the rainfall been normal in 1930, there is every possibility that the level of parasitism for that year would have shown a greater increase over 1929 than is actually recorded.

Table I, therefore, shows that the extensive data collected on field parasitism for a period of six months in each of five years, give reasonable indications that the level of parasitism has risen with annual increased liberations of parasites (see Graph I) despite the fact that collections were made in fields selected at random irrespective of whether they had been colonised by their respective plantations or not, and despite the operation of very different annual climatic conditions, combined with the operation of the Malthus law of parasitism and population, on a naturally fluctuating *Diatraea* egg deposition, and despite the fact that during the first few years of parasite liberation, colonisations reached their maxima in different months, and were spread over different periods, until experience showed the best time for maximum production, and the limit of period over which to make liberation.

Previous examination of field data (11) and (13) and (14) has shown that increased parasitism of *Diatraea* eggs raises the final mortality rate of *Diatraea,* and has shown that relatively small fluctuations in the rate of total real mortality are capable of causing considerable differences in the accumulated damage caused by *Diatraea* as recorded at crop reaping.

Therefore the increase in annual *level* of parasitism shown in Table I, and Graph I, can be held to be connected with the annual reduction in percentage infestation of stalk internodes determined each reaping time, and shown in Graphs III to VI, and in conjunction with other data given, to be a contributory cause towards increased purity of juice in factories and increased total crop of sugar.

Before leaving the subject of determination of increase in parasitism of *Diatraea* eggs, and decrease in damage due to liberation of *Trichogramma,* it may be as well to refer to the possibilities of obtaining direct field evidence on these points from experimental plots laid out in conformity with statistical requirements.

This has always been recognised as the requirements of accurate scientific investigation but to carry such experiments out on an adequate scale is an undertaking of a magnitude which places it beyond the resources of the Department of Agriculture. It is not necessary to give details of the size and scope of experiments with the necessary complements of replicate and control plots or to enlarge on the trained staff necessary to make the requisite bi-weekly counts and records of egg deposition and parasitism over the whole series.

What can be stated is that in 1934 a definite experimental comparison was made between an adequate colonised area, and a non-colonised area. It is hoped to publish details of this experiment later, showing the work involved in making

adequate counts in one colonised, and one non-colonised area only, when each is of an adequate size for such an experiment. The results are as follows, using the variety B.726 only; the low parasitism for 1934 can be attributed to the exceedingly dry conditions experienced in that year.

TABLE II.

Percentage Parasitism by *Trichogramma* of *Diatraea* eggs in Experimental Plots 1934.

	March	April	May	June	July	August	Sept
	%	%	%	%	%	%	%
Colonised ...	8.3	15.5	11.3	27.5	57.4	51.2	31.8
Uncolonised	7.1	3.4	6.9	11.6	25.2	22.0	14.3

This, together with the experiment as given on pp. 36 to 37 on counts of bored internodes in an area of one field in which parasites were consistently liberated, compared with the remainder of the field where no liberations were made, are at least reasonable indications that the accumulated evidence in favour of a reduction in *Diatraea* infestation since, and due to, *Trichogramma* liberations is correct.

(b) THE EFFECT OF EARLIER AND INCREASED COLONISATIONS OF TRICHOGRAMMA.

The second question, namely, whether earlier and increased colonisations of *Trichogramma* cause earlier and increased rises in field parasitism can definitely be answered in the affirmative. In each year that colonisation of mass-reared parasites was commenced earlier than before, the majority of fields examined showed an earlier and increased rate of parasitism by *Trichogramma*. (See April records, Table I.)

(c) EFFECTS OF INCREASED PARASITISM.

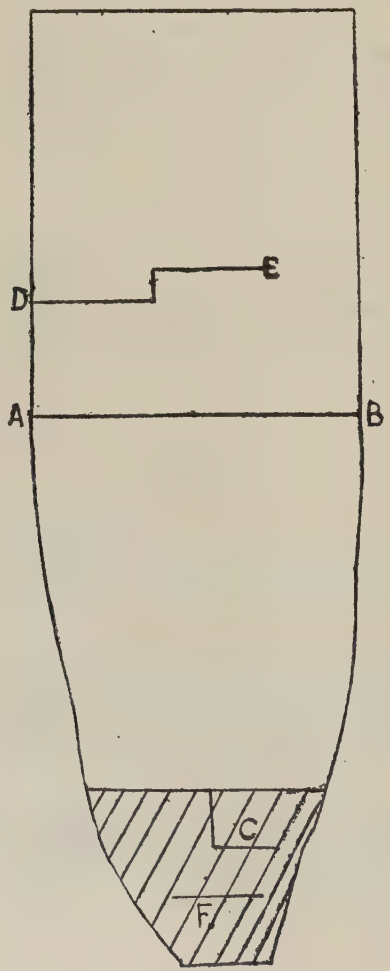
The third question as to whether increased egg parasitism results in a measurable diminution in larval population and therefore of damage caused by borers is answered by field results, factory results, and by the mathematical examination of the problem given in (14) wherein data are analysed over a period of five months instead of two as in (13).

The field results referred to above, as furnishing proof of reduced infestation of *Diatraea* due to liberation of *Trichogramma*, are those carried out over a series of six years by Dr. Hinds and his co-workers in Louisiana (2), (3), (4), (5), and (7). The writer has seen no reason for duplicating these experiments on a statistical scale in Barbados.

Two field experiments were, however, carried out in Barbados in 1933; one at the Government Station at Codrington and one at the Government Reformatory School Farm at Dodds, and the results are worth recording.

The first experiment was not deliberately planned and consisted of the results obtained by counting bored joints in *canes reaped* from 18 blocks of 12 randomised plots each of 12 varieties of cane, to obtain data on varietal susceptibility to borer. These extensive counts showed that standard varieties in those plots which were supplied regularly with parasites, were less infested with borer, as shown by percentage joints bored, than were the same varieties grown under plantation conditions, with fewer parasite liberations. Thus the figures obtained from the experiment at Codrington in varieties which are the standard ones found in factory yards were Ba.11569, 10.07% joints infested; B.726, 10.00%; B.891, 11.51%; whereas the average infestation of all canes of these varieties examined during the annual factory survey showed Ba.11569 with 12.28% joints infested; B.726, 13.47%; and B.891, 20.15%. Thus the extra liberation of parasites in the varietal plots resulted in a decrease in infestation in those varieties under normal field liberation, the extent of which is acknowledged to be still far from complete.

The second experiment was a direct comparison between a colonised and a non-colonised area. A long isolated field of B.726 was chosen and parasites placed regularly in 50 rows of cane, comprising around two-thirds of an acre at one end as in sketch.



When reaped, canes were examined as cut by the reapers at C and at F, and from A to B and from D to E. Counts at C and from A to B were made one day, and at F, and from D to E on the next day, as reaping progressed to these points. At C, percentage joint infestation was 6.96%, and at A to B, examined at the same time, it was 15.93%. At F, infestation was 6.09%, and at D to E, 19.92% joints bored. This indicates that a certain amount of 'protection' from the parasitised area extended as far as A to B, and that had examinations been made still further away than E, greater infestation even than 19.92% joints bored would have been found in the uncolonised area. This experiment, therefore, is again an indication of the effectiveness of *Trichogramma*, in reducing *Diatraea* infestation, and supports other indications and proofs submitted in this paper.

It has been shown now that field colonisations of *Trichogramma*, result in an increase in the percentage of *Diatraea* eggs parasitised, and in a definite lowering of the damage caused by *Diatraea*. This diminution in damage is illustrated by the following graphs.

When comparing these graphs, it should be borne in mind that the exceedingly dry conditions experienced in 1930 are reflected in field parasitism for that year, but in crop *records* for the following year.

Also that Graphs II and VI are complementary; that is, total loss of canes in the field should be considered in relation to factory loss as indicated by average percentage of internode infestation; thus in 1932 a rise in the field loss is compensated for by a very large drop in the factory loss. This effect has been commented on in other publications.

Further, in Graph VII, a potent contributory cause to the increased juice purities shown is the rapid increase in the amount of the varety B.726 from 1930 onwards as described on p. 38.

Graph I. Percentage field parasitism of *Diatraea* averaged for around 40 fields over a period of 6 months in each year, plotted together with corresponding liberations of *Trichogramma* for each year*

Graph II. Percentage total loss of canes, varieties Ba.11569, B.726, B.891, B.H.10(12) and B.417 averaged from 100 stools in each of 60 odd fields throughout Barbados for each year except 1929 and 1930. In these two years only three or four fields were sampled in areas to which, at that period, parasite liberation was restricted.

Graph III. Percentage infestation of joints of variety Ba.11569 at 7 Factories representative of the drier areas of Barbados. Plant Cane.

Graph IV. Percentage infestation of joints of variety B.H.10(12) Plant Cane at 7 Factories representative of the wetter areas of Barbados.

Graph V. Percentage infestation of joints of variety B.726 Plant Cane at 6 Factories representative of both wet and dry areas. Extensive plantings of this variety, giving records at several factories have only been available in recent years.

Graph VI. Average infestation of all varieties namely, Ba.11569, B.H.10(12), B.726, B.891, B.374, B.663 at 12 Factories. Plant Cane.

Graph VII. Percentage juice purities averaged over a comparable period of several weeks at 5 factories in the area of longest parasite liberation (i.e. from 1929).

Examination of the records taken each year from fields irrespective of whether they were colonised or not, shows that the level of field parasitism of *Diatraea* eggs by *Trichogramma* has shown a fairly regular upward tendency with increased parasite liberations. Coincident with the increase in destruction of *Diatraea* eggs, caused thereby, and with the increase in total real mortality as shown by the mathematical examination of field data given later, there is a decrease in damage caused by moth borer. The latter is shown by field records

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* See footnote p. 32.

of diminution in total loss in each crop due to canes destroyed in the field, and by factory records of diminution in percentage of joints bored, variety by variety, and in total.

If this increase in damage to canes at factories is fact, there should be an increase in purity of juice milled at various factories. An increase in purity of juice over the years of parasite liberations has been reported by most factories, and is shown by the plotted records available from five of the principal factories in the areas in which parasites have been liberated since 1929, and from which continuous and comparable records are available. These factories are Kingsland, Bulkeley, Carrington, Three Houses and Andrews. The fact that these increases in juice purities are consistent and have been obtained from five factories over a period of six years, greatly minimises the effect of climatic or other factors likely to cause a rise or fall in juice purities, and makes it probable that the steady increase in juice purity shown, is *in part* due to the decrease shown in borer damage. No claim is made that the total increase is due to the lessening of borer damage, since it is known that the increased plantings of B.726 since 1930 (inclusive) have resulted in an increase in the sucrose content of the juice milled in 1931, 1932, 1933, and 1934.

Finally, if there is an increase in purity of juice due to less borer damage at factories, and an increase in tonnage of canes reaped, due to decrease in the amount of cane totally destroyed by borers in the field, it would be expected that there should be an increase in the amount of sugar produced by the Island.

Any such increase, due to reduction in loss and damage due to *Diatraea* could not be expected to be very apparent in the crops affected by the parasite liberation of 1929 and 1930, for these liberations were made mainly over a portion of the Island only, and though providing data showing increased parasitism and decreased *Diatraea* injury in those areas, would not affect the total tonnage to the extent that climatic and other conditions (as enumerated below), are likely to have affected the tonnage.

From 1932 onwards, however, parasite production was doubled, and in one instance, trebled, and the whole Island received distributions of parasites. In these years increased production of sugar by the Island as a whole is most marked; once again, however, no claim is made that the entire increase is due to control of *Diatraea* for reasons given below.

It is naturally a matter of some difficulty to say exactly what increase in sugar tonnage is due to decrease in damage by borer; nevertheless, if an economic reduction in borer damage is claimed, it is expected that some figures should be available to substantiate the claim.

This, it is reasonable to consider, is shown by the peak tonnage of 1933 (grown in 1932—33 the first year of Island wide colonisation) which produced an increase of 27,000 tons over the highest tonnage in the years just prior to control work.

Assuming that of this increase, 75% is due to the following factors:—

(a) increased rainfall;

(b) more scientific manuring and early mulching of young fields;

(c) increased plantings of B.726, and trials of new varieties;

(d) better machinery and factory practice;

(e) to the measure of control so far effected over root borer and brown hard back;

(f) to there being from 3,000 to 5,000 more acres of land retained or put under cane in 1932;

there still remains an increase of around 7,000 tons of sugar which can reasonably be estimated as due to reduction in loss and damage caused by *Diatraea saccharalis*. This amount at £10 a ton (the average price in 1933) is £70,000 in one year only, for an expenditure of £525 in wages, material and upkeep, plus salaries; a total of say £1,500.

The extent of control obtained can therefore be called economic, though it is not to be expected that the increase in crop will always be as great every year as in the instance given above.

The remaining investigation under II (c), namely the mathematical consideration of the effect on total real mortality of *Diatraea* caused by raising the level of parasitism of *Diatraea* eggs by means of mass bred and colonised *Trichogramma*, has been dealt with in (13) and in (14) and can be summarised as follows.

The variable field or 'apparent' values of various mortality factors operating on the *Diatraea* cycle which have been described in (13) are capable of determination week by week for at least nine months of the year, i.e from January to September. Unfortunately, it is not possible to obtain a series of observations on all mortality factors for every month; and any month in which one of the variable factors has not been determined, has to be omitted from calculations.

For a period of five months, however, in Barbados, namely May to September, it has been possible adequately to determine all the mortality factors operating on the *Diatraea* cycle, with the exception of adult moth mortality which as stated in (11) is assessed at a maximum of 15.0%.

These mortality factors are:—Egg sterility, F 1; egg parasitism, F 2, eggs destroyed by predators, F 3; early larval mortality, F 4; (late larval mortality due to fungus *Cordyceps* is small and mortality due to insect larval parasites is non-existent at present in Barbados); and finally adult moth mortality, F 5.

The presence of each factor obviously affects the value of the subsequent factor, making its real mortality less than the apparent field mortality. The real mortality value of any factor F 2, F 3, etc., can be determined from its field value by the use of Dr. W. R. Thompson's formulae as given in (9) which have been adapted to the *Diatraea* cycle by the writer in (13). Thus the *total real mortality* of all factors can be determined for any one period at which these factors are determined.

The various factors vary with the stage of cane growth, extent of parasite liberations and climatic and other factors. It is not valid to determine the apparent values of mortality factors at *different* periods of the year and then to combine them in Dr. Thompson's formulae. All factors must be determined at the same period, and the results obtained, of total real mortality of *Diatraea*, then apply to that period only.

The writer has stated in (11) and in (13), that the calendar month is the most convenient unit to adopt as providing sufficient time to carry out an adequate series of observations for the determination of field values of mortality factors, and as being a reasonable period over which the factors so determined can be considered as operative.

Having determined the field or apparent values of mortality factors, Dr. Thompson's formulae, as given below, enable the real values to be determined thus. If A, B, C, D, etc. represented the *real* fractions of total initial population destroyed by each of the factors F 1, F 2, F 3, F 4, and a, b, c, d, represent the *apparent*, or field determined destruction, then the relation of real to apparent destruction is as follows:—

Factors.	Apparent destruction.	Real destruction.
F 1.	a.	A=a
F 2.	b.	B=(1-a)b.
F 3.	c.	C=(1-a)(1-b)c.
F 4.	d.	D=(1-a)(1-b)(1-c)d.

The sum of the real destruction due to each factor then gives the percentage real destruction caused by the operation of known mortality factors over a given period. The balance obviously gives the amount, or percentage, of initial population which survives during that period. Therefore, if one can determine the total initial population per acre, and if one knows the extent or amount of host plants available per acre *at that period*, it is possible to form some judgment as to the amount of the crop likely to be damaged and thereby to check the field determinations of damage. The writer has obtained this necessary data, and carries the above statement into effect in (14).

It is also possible to say whether any new control measure, or projected combination of measures, is likely to reduce infestation; and whether the cumulative effects of monthly reductions in infestation in a crop of long growth period such as sugar cane, is likely to be reflected at crop reaping time in a reduction in the total damage at that period. These points are set out in (13) and are carried to their logical conclusion in (14).

It remains to add that the data in these papers refer to conditions in 1933 only; but that these results have been fairly general during all years of parasite liberation is shown by Graphs I—VII given above.

(d). DO THE FOREGOING FACTS RESULT IN THE PERMANENT LOWERING OF DIATRAEA POPULATION?

There is now the final point as to whether the decrease of infestation by *Diatraea* which has been proved in this paper for a period of six years is likely to be permanent. That is, if *Trichogramma* breeding and liberations were stopped, would *Diatraea* infestation remain at the reduced levels shown in recent crops reaped? In the opinion of the writer it would not. This is because the total initial borer infestation of the new, young crop starts from a low level each year derived mainly from the adjacent fields of old crop. Any reduction in this low level which might be caused by a reduction in the amount of damage to, or even of final borer population of, the old crop, is not likely to be greater than fluctuations caused by climatic factors at that period.

In addition, it is not claimed that final infestation, or population level, of *Diatraea* is reduced by the action of *Trichogramma* during the period of 26—28 weeks of mass liberations. It *is* claimed that the liberations during this period (which includes the most critical period of cane development and growth, and coincides with the period of most rapid increase of *Diatraea*) reduce the extent of damage inflicted on the canes, so that, as stated, it is apparent in canes examined in fields and at the factories at reaping time.

Subsequently, when *Trichogramma* liberations cease, it is possible during the ensuing five to seven months before the crop is reaped, for the borer population gradually to recover its lost ground—which is suggested by the prevalence of *Diatraea* damage to the top portions of the canes in growth made, say, from November onwards. Thus although the total damage to canes may be reduced each year, yet final borer population of all fields, and therefore initial borer population of young fields, may remain fairly constant.

Initial infestation of young canefields is also derived from planting infected seed cane, and therefore a reduced borer population around November might reduce the amount of infestation transferred to new fields in the pieces used for seed. In this case, however, there is reason to believe (6) that the moths which are capable of emerging from planted, bored seed are not a great source of damage, but that the real loss due to planting bored seed cane is caused by the damaged eyes of the bored seed resulting in a poor spring, which necessitates 'supplying' the failures.

It is the writer's opinion that with normal variable climatic conditions, it is not the low initial or high final population of *Diatraea* in cane fields which counts, as much as the suppression of *Diatraea* population during the 26—28 weeks of *Trichogramma* liberations, from March to September.

If, during the limits of this period, *Diatraea* can be controlled economically as it is by systematic or regular liberations of *Trichogramma*, then the final damage to crop when reaped can be lowered as shown by the foregoing results, in proportion to the number of *Trichogramma* liberated annually, even though the lowering in *Diatraea* population is not permanent.

The aim of this paper has been to set out the case for *Trichogramma* as a control for *D. saccharalis* in cane, in the light of a full examination of the data collected by the writer and by the Staff of the Department of Science and Agriculture in Barbados over a period of six years. From all angles of examination the results either prove, or else indicate, the success of this method of control in reducing *Diatraea* infestation.

It may still be held that the proof is as yet scientifically incomplete, though the work in Barbados does not stand alone, but is re-enforced by similar work and results in other sugar growing countries.

It is realised that this paper does not by any means exhaust the scope of research on *Diatraea* in sugar cane, or the possibilities of its control. Work is now in progress on the effect of different cane varieties on the egg laying capacities of *Diatraea* in the field; and on the resistance of cane varieties to infestation by the larvae of *Diatraea;* and it is possible that from these studies information may be obtained which will be of assistance to the Central Cane Breeding Station in Barbados, and result in the future selection of borer resistant canes, whereby *Diatraea* infestation will automatically be checked. The introduction of larval parasites of *Diatraea* in Barbados, is also being effected, for although infestation now stands at, and can be maintained around the figures given in the foregoing results, there is still room for further reduction in infestation. The larval parasites which are being introduced are *Lixophaga diatraea* from Cuba (obtained from Antigua, where it is hoped it has become acclimatised) and *Paratheresia claripalpis* obtained from Trinidad. Both are being laboratory reared, and will be liberated in sufficently large numbers (in the wet and dry areas respectively) to give them every chance, and adequately to test the conclusions reached in (13).

SUMMARY.

1. The conditions which exist in cane fields when *D. saccharalis* is in normal equilibrium with its usual field mortality factors are stated, and evaluated, as far as present research permits.

2. The conditions which are created by increasing the mortality factor due to destruction of *Diatraea* eggs by *Trichogramma* are stated.

3. The results obtained by six years of general field observations and analyses of data obtained from recent experiments are described.

4. The control over *D. saccharalis* which results from the continuous and increased large scale liberations of *T. minutum* throughout a period of 26—28 weeks of critical cane growth is demonstrated in Graphs I—VII.

5. These graphs, which are based on extensive and impartial Departmental field records show that as the annual production and liberation of *Trichogramma* increased, so average field parasitism of *Diatraea* eggs, increased. Following this, the average field loss of cane totally destroyed and rendered unreapable by borer is shown to diminish year by year, and factory loss as shown by the percentage of cane joints damaged by borer is also shown to diminish year by year. The diminution in percentage of joints bored in plant cane is clearly shown by sorting out varietal records over a period of four or five years at the various factories, and by the average infestation of cane at all factories visited at each annual survey. Moreover, as the percentage of joints bored throughout the island is reduced each year, so an increase in purity of juice at factories should be expected each year. This increase in juice purity has been obtained, but undoubtedly the rapid increase of the B.726 variety has improved the juice very considerably.

6. As purity of juice at factories has been increased to some extent, and total loss of cane in the field has been decreased, there should be an increase in total tonnage of sugar each year. This has also been obtained, and the economic result is evaluated.

7. The question of permanent benefit resulting from annual liberations of *Trichogramma* is discussed and it is concluded that, as initial infestation of young cane fields is automatically reduced to a minimum each year, any reduction in this minimum due to reduction in the amount of damage in the reaped cane, is not likely to be greater than fluctuations caused by climatic factors; moreover a reduction in the total amount of *damage* at reaping time does not necessarily imply a reduction in the numbers of *Diatraea* which exist each year at reaping time, several months after the discontinuation of *Trichogramma* liberations. The continuation of *Trichogramma* liberations is therefore considered as a permanent necessity, but as eminently practicable on account of the ease, cheapness, and economic effectiveness, of routine mass rearing of *Trichogramma.*

8. A map is given showing the areas of the island covered by each annual survey of damage to crop.

9. Appendices are given on Temperature and Humidity Records inside a canefield, and on Notes on Early Larval Mortality.

APPENDIX I.

RECORDS OF TEMPERATURE AND HUMIDITY INSIDE AND OUTSIDE OF A CANE FIELD.

This work has consisted in Barbados of placing inside a cane field a recording hydrograph and a recording thermograph housed in a wire netted cage, roofed, and with the side exposed to wind and rain single louvred to afford protection to the instruments. This type of cage allowed a more accurate recording of conditions in and under the cane leaf canopy than would the usual completely double louvred meteorological instrument housing. A similar cage outside the canefield contained a recording hydrograph only, external temperatures being taken as those recorded normally for that area at the nearby Codrington Meteorological Station. A comparison of graphs recorded weekly in the above manner inside and outside a cane field for six months (end of May to end of November) shows definitely that in both cases the moisture content of the air is lowest at noon and highest at midnight.

Whereas, however, the noon low is reached by a fairly sharp but irregular drop from between 7.00 and 8.00 a.m. to 12 noon remaining low till 1.00 —2.00 p.m. and then rising sharply again but slightly more regularly from between 2.00 and 4.00 p.m., and 6.00 and 7.00 p.m., the night time high moisture content is reached around 8.00 p.m. and usually remains at that level, with slight fluctuations, till around 8.00 a.m. *Diatraea* moths thus have optimum humidity conditions during their egg laying periods.

The inside and outside humidity records corresponded in all major details of rises and falls, etc. but in practically every case the readings were higher inside the canefield, and differences between maximum and minimum readings were also invariably greater. Difficulty was experienced in keeping the two instruments recording equally, and the newer instrument placed inside the canes tended to record higher than should have been the case. Nevertheless, results were substantially as above, and there was quite definitely a greater average humidity and in most cases a greater range of humidity, inside the canes compared with outside.

Temperature records were kept as detailed above, over a period of five months (June to October), by a thermograph inside the canefield and by maximum and minimum thermometer at the Codrington Meteorological Station about half a mile away from the cane field.

A comparison of these records for a period of five months shows a daily maximum thermograph reading which was *always higher* inside the cane field by 7° F. to 11° F. than the maximum thermometer reading at the Meteorological Station; and a daily minimum reading *lower* by 2° F. to 8° F. Thus, for example, the maximum record inside the cane field would be 92° F. and outside, it would be 85°F; the corresponding minimum readings being 70° F. inside and 75° F. outside the field. Very occasionally the minimum reading would be the same in both cases, but in no case was a higher maximum temperature recorded outside the canes than inside.

In June to October, the difference between maximum and minimum temperatures inside a cane field measured by thermograph was between 18°F. and 25°F., the most frequent difference being 20°F., whilst outside the cane field (measured by maximum and minimum thermometers) the difference between maximum and minimum temperatures was between 10°F to 12° F. the most frequent difference being 10°F.

Hence, inside a cane field the range of temperature is from 8° F. to 11° F. greater than outside and may rise to over 95°F.

In October and the latter part of September the range of temperature registered outside the cane field increased slightly, so that the difference between temperature inside and outside the cane field becomes slightly less.

The above statements are generalisations from daily records made from June to October, 1933, and show that temperature conditions are markedly different inside cane fields, to those obtaining outside the fields, the difference being probably due to extra moisture due to plant transpiration and to lack of wind penetrating the canes during the day, and to lack of soil radiation during the night.

The above generalisations on humidity and temperature in the insects' environment, are made from records which are as exact as available apparatus permitted, and as near to true conditions inside and outside a cane field as circumstances permitted. It is recognised that the study of micro-climate as it affects insects, is a specialised and detailed procedure, and should be correlated with equally detailed meteorological data and with laboratory data on the reaction of *Diatraea* to condition discovered. Such work, of course, has not been possible, but as a basis for further investigation these records may have some value.

APPENDIX II.

NOTES ON EARLY LARVAL MORTALITY.

It is granted that only a varying proportion of *Diatraea* eggs deposited each night develop successfully and produce larvae. What happens to the larvae which succeed in hatching out, between the time that they wander away from the egg cluster, and the time that a varying proportion succeed in developing sufficiently and establishing themselves in positions where they can reasonably be expected to continue their development through to pupal and adult stages?

The information on this period of life history appears to be rather meagre though Holloway, Haley and Loftin (1) give an interesting account of larval food habits.

The writer therefore feels justified in recording the following observations:

Larvae have been observed in the process of hatching from egg clusters in the field early in the morning, and being weakly positively phototropic, the majority usually move towards the source of greater light intensity, namely East at that time of day. This meant that the larvae moved down the leaf towards the cane stem or up the leaf towards the tip, according to the general direction in which the leaf pointed. Those that moved towards the cane stem were lost sight of; penetration of cane spindles or stems was not seen, but when plots of young canes were reaped month by month, and examined in detail leaf by leaf and shoot by shoot, young larvae were found boring in midribs, leaf spindles and basal leaf sheaths, giving rise later to characteristic *Diatraea* injury. Larval attempts at boring into stems were also seen in these plot examinations, but, in a large number of cases, the causal larvae could not be found. It is possible that of these larvae, weather conditions or lizards or spiders may take their toll as the larvae wander, but it has always appeared to the writer that the majority of such larvae which do not succeed in entering the canes under these conditions, are inherently unable to do so. That is to say the greater proportion of larvae from the greater proportion of egg clusters are physically unable to feed and develop sufficiently on vigorously growing cane shoots to effect permanent and successful penetration; on the other hand, *all* the larvae from some egg clusters may be physically capable of survival, with the result that here and there one finds cane stools or groups of stools riddled with borers. The high rate of survival of larvae from individual masses and the inability of larvae from other masses to survive under similar conditions, has been observed by Dr. G. Wolcott in the case of larvae hatching from egg masses of *Diaprepes*, and it has for some time appeared to the writer that a similar phenomenon occurs in the case of *Diatraea* eggs. If this is so, it would be a contributory cause to the very irregular intensity of infestation found in cane fields and for which other contributory causes are suggested in (10) and (11).

The larvae which proceed towards the tips of cane leaves, wander actively, and may pass directly on to other canes by means of interlocking leaves, or lower themselves by slender threads to other leaves, or may drift away on light winds

in the same manner that young spiders do, or may be blown away by stronger winds. The latter has been definitely observed by the writer; twelve newly hatched larvae were found one morning quiescent besides their egg cluster on the outer surface of a young cane blade in January. The cane blade in which they were thus resting was held by the writer so as to lie east and west; as the sun's rays struck the larvae, they began to move, and six proceeded without hesitation towards the sun which led them down the cane blade to the shoot. The other six wandered vaguely for a period; then two more proceeded directly toward the shoot and four went away from the stalk, i.e. they were not strongly positively phototropic and kept straight on to the leaf tip. Two out of the three disappeared from the edge of the leaf and one held on to the tip where, under the hand lens, the writer observed it to flex its body and apparently launch itself into the breeze which was blowing fairly strongly from the northeasterly direction.

Larvae have also been caught by the writer on tanglefoot sheets fixed to boards at some distance to leeward of cane fields; which is in keeping with the wind drift or transportation of larvae. The fact that young cane stools can be found on which an egg cluster, or clusters, have hatched, but in which no larval damage can be seen, does not necessarily mean a 100% larval mortality; the larvae may have migrated. This view is supported by the definite fact that young cane stools can be found in which larval feeding is definitely present and in which dead hearts and *living larvae* can be found, though *no egg masses* are present, or have been found in such stools.

During this period of migration and external feeding, Holloway, Haley, and Loftin state that the young larvae are cannibalistic; the writer has never observed this, though there is reason to believe that they are cannibalistic when confined in numbers with cane shoots in jars.

Once larvae have penetrated canes or shoots and reached the second or third instar, they become negatively phototropic, seeking dark places and only migrating from young cane shoots when the shoot dies or rots extremely before they are ready to pupate; they appear, however, to tolerate considerable liquefaction and decay of the cane shoot tissue.

Diatraea larvae are capable of being drowned, though, according to the treatment required for infested cane seed. (i.e. cuttings) it takes nearly 72 hours submergence to kill them. Wolcott has recorded (15) that "larvae were found which had been drowned in a mixture of water and decaying cane juices which had collected in their tunnels after rain," showing that rainfall can, under some conditions destroy *Diatraea* (presumably nearly fully grown larvae). Dr. Wolcott also records the effects of rainfall on *Diatraea* larvae, and the possibility of drowning in his Economic Entomology of the West Indies (14), pp.181–182.

Holloway, Haley and Loftin, (op. cit.) however, record that "young larvae have also been observed to crawl down into a bud which was completely submerged and feed for several hours under water without any apparent discomfort.

The two observations are not necessarily at variance, because it would appear that adult *Diatraea* larvae can also tolerate several hours' immersion in water,

which necessitates the 72 hours' submergence of 'plant' canes to drown the larvae therein.

It is interesting, however, to know that rain does not necessarily kill young or maturing *Diatraea* larvae, but that under some circumstances they can be drowned.

The point is of interest, because opinion on the effect of rain on *Diatraea* prevalence is definitely at variance. Thus, Dr. G. Wolcott, who has studied *Diatraea* in various South American and West Indian areas states (15) that "In general, the per cent. of infestation was inversely proportional to the rainfall; that is, an abundance of rain meant few borers, and little rain meant many borers." Whereas, Dr. J. G. Myers, who has also studied *Diatraea* in many countries states (8) that "other things (especially parasites) being equal, the *Diatraea* infestation from estate to estate and from colony to colony varies directly with the rainfall."

These opinions are diametrically opposed, and the writer has not at present sufficient direct evidence to say which one is correct. It is possible, however, that high or increased rainfall may be detrimental to the survival of *Diatraea* larvae, but favourable to larval development and to increased egg deposition; and that the balance is slightly in favour of high or increased rainfall being favourable to *Diatraea* infestation. This theory, of course, presupposes the absence of any larval parasite which is also favoured by increased rainfall and does not take into account the detrimental effect of lack of sufficient rainfall on the egg parasite *Trichogramma*.

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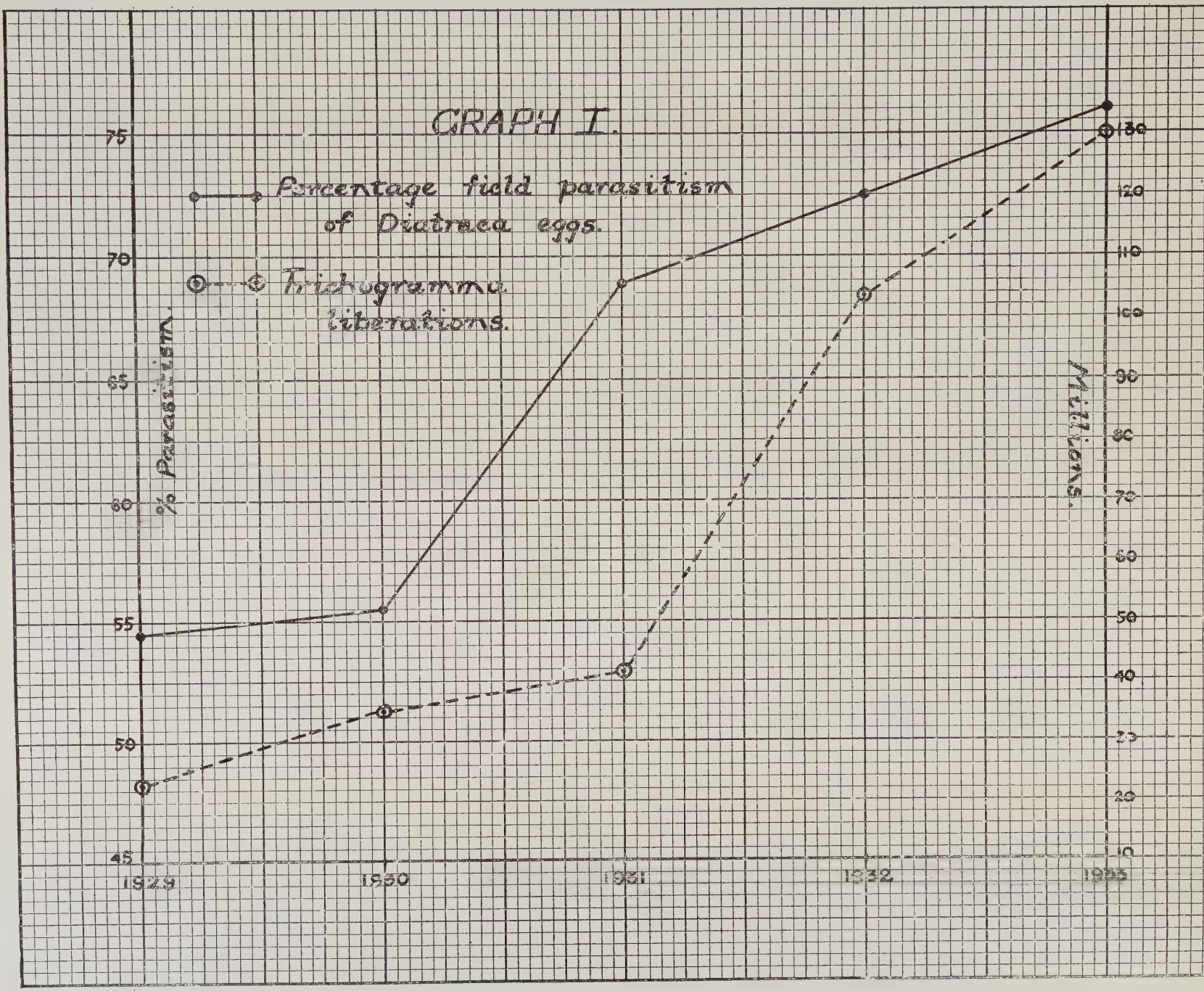
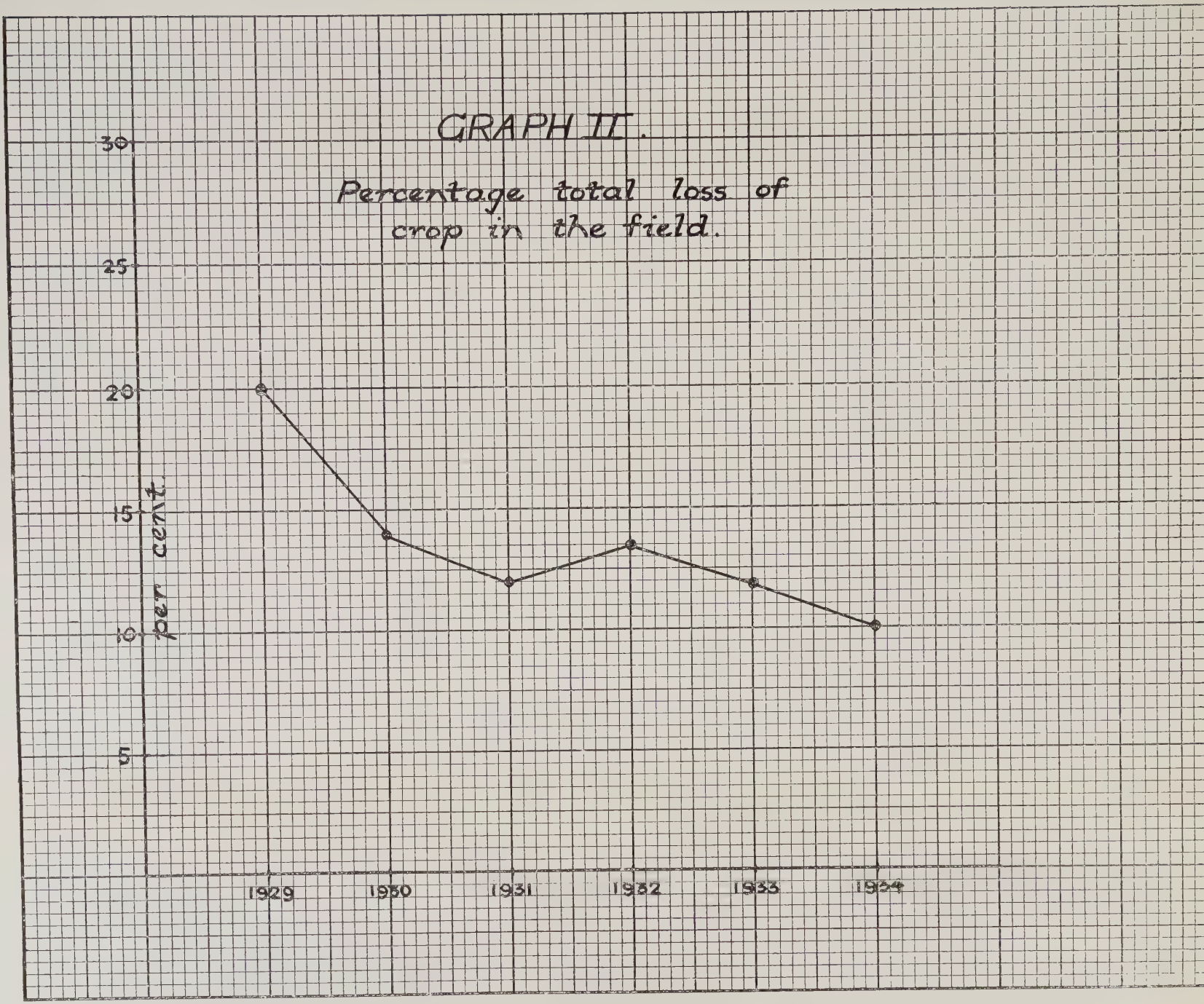
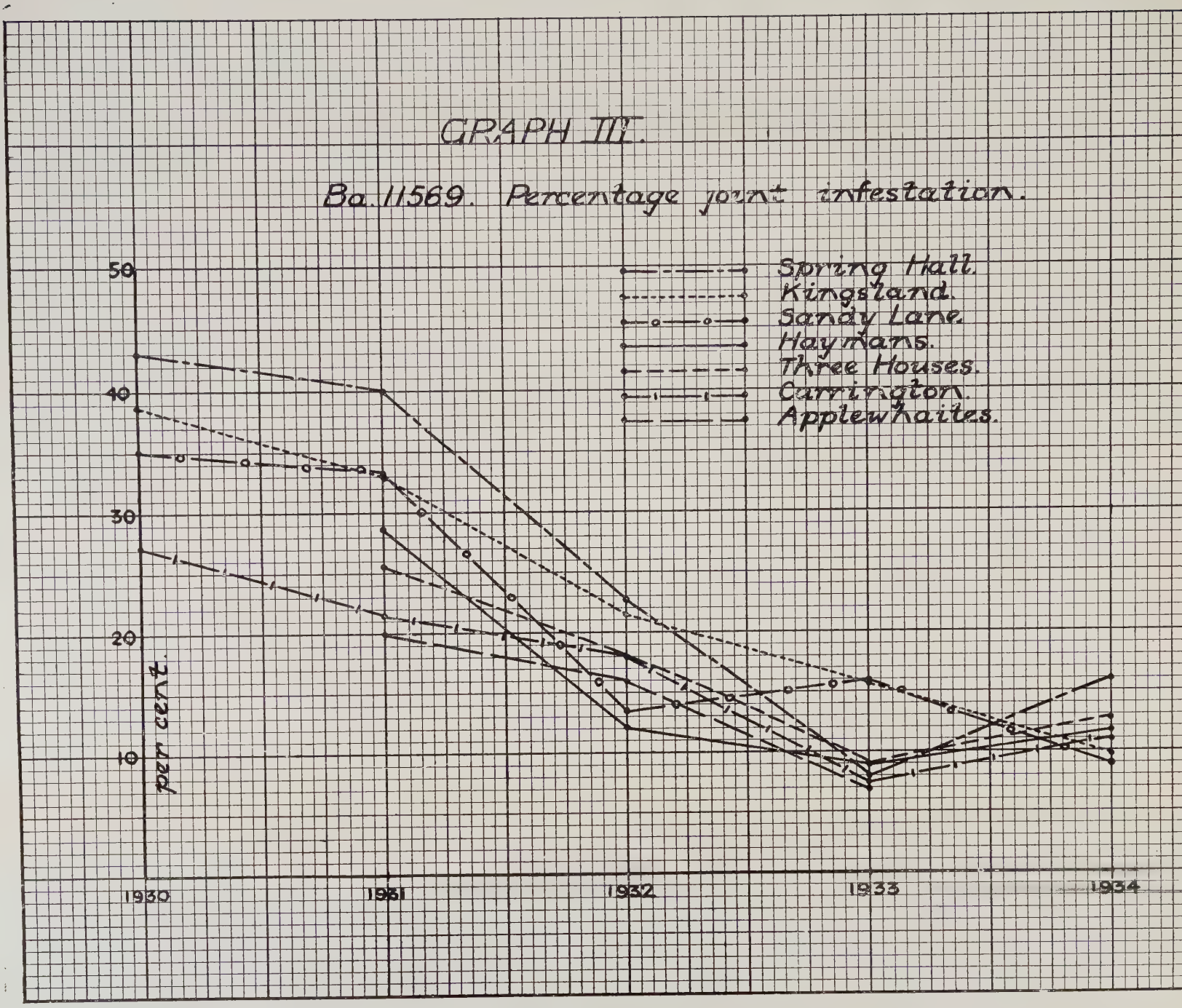

GRAPH I.
Percentage field parasitism of Diatraea eggs.
Trichogramma liberations.
% Parasitism.
Millions.
75
70
65
60
55
50
45
130
120
110
100
90
80
70
60
50
40
30
20
10
1929
1930
1931
1932
1933

GRAPH II.

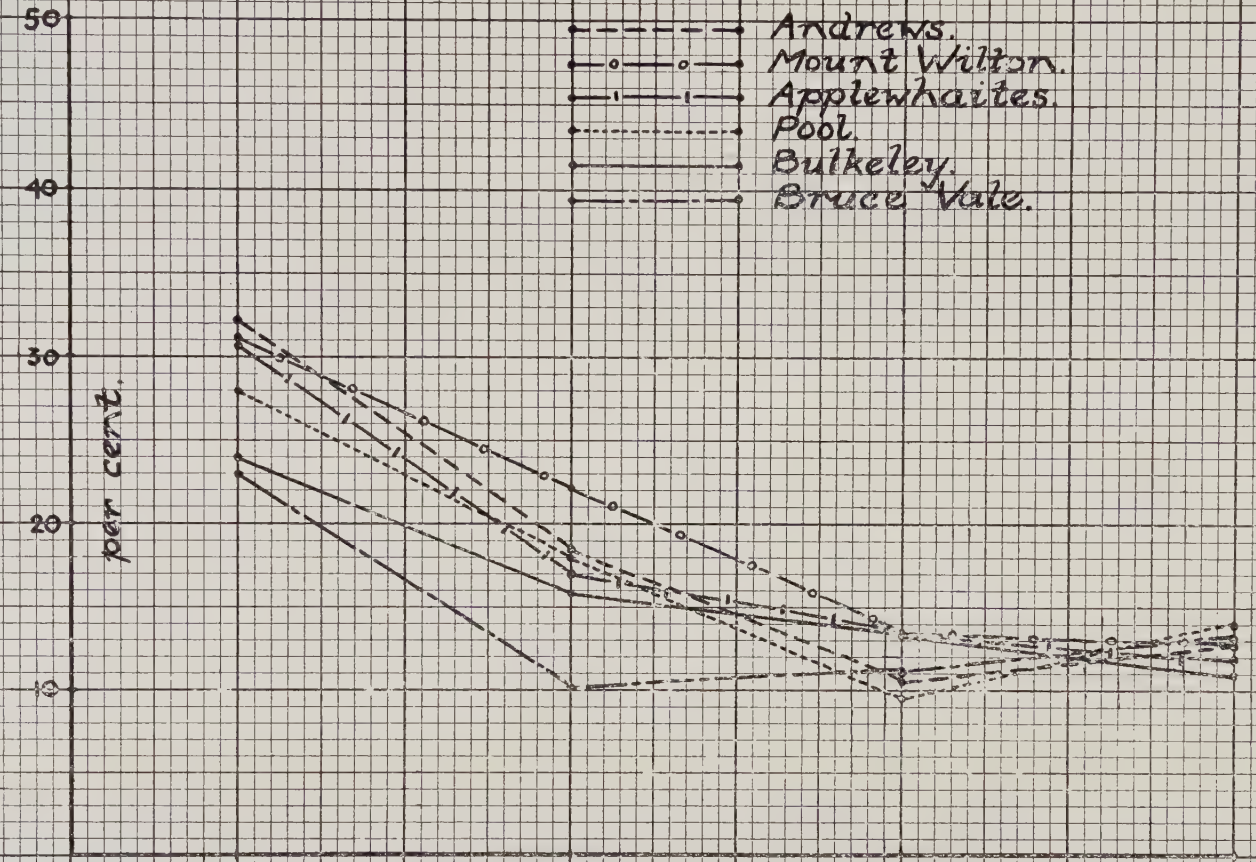
Percentage total loss of crop in the field.




GRAPH III.
Ba. 11569. Percentage joint infestation.
Spring Hall.
Kingsland.
Sandy Lane.
Haymans.
Three Houses.
Carrington.
Applewhaites.
50
40
30
20
10
Per cent.
1930
1931
1932
1933
1934

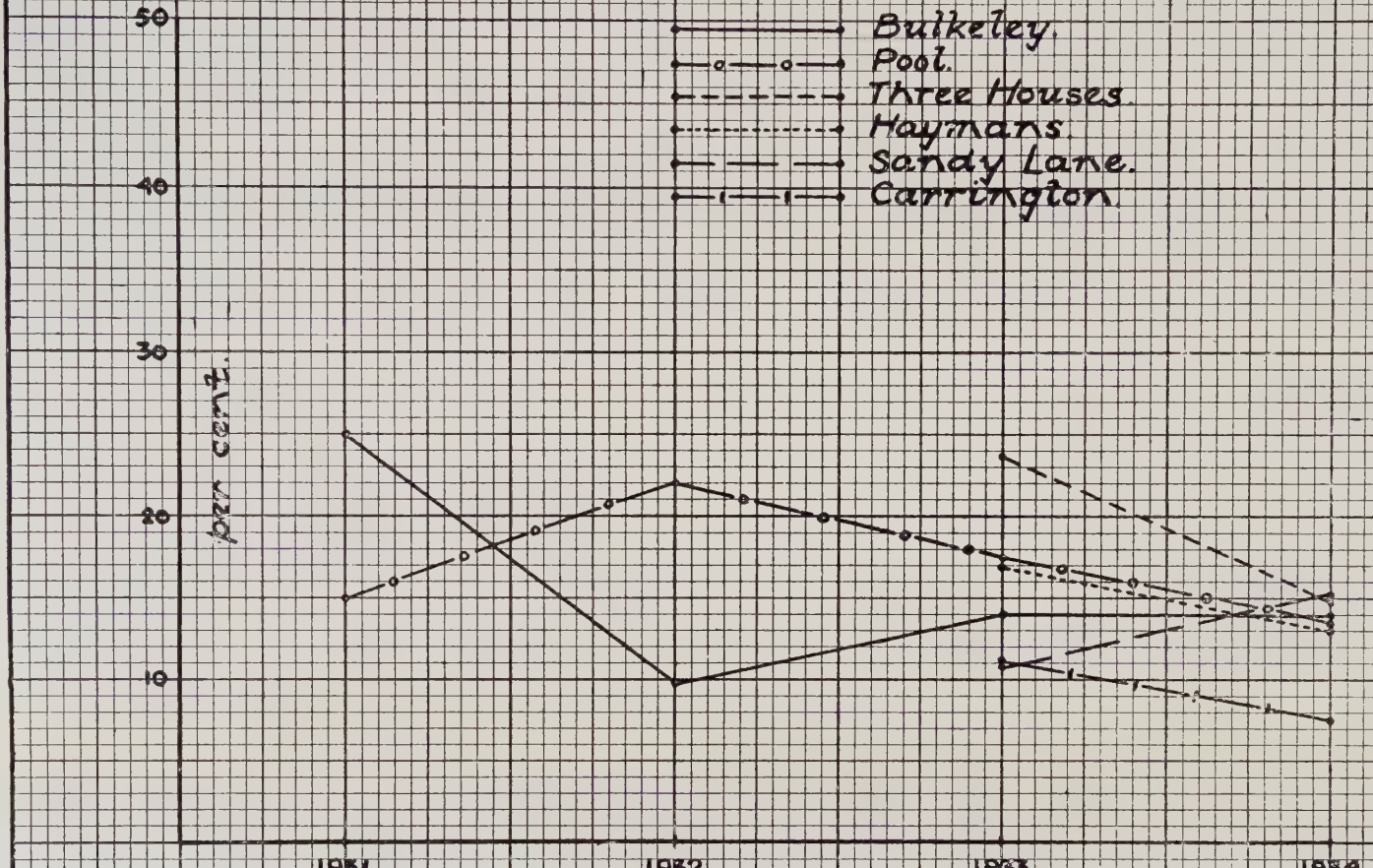
GRAPH IV.

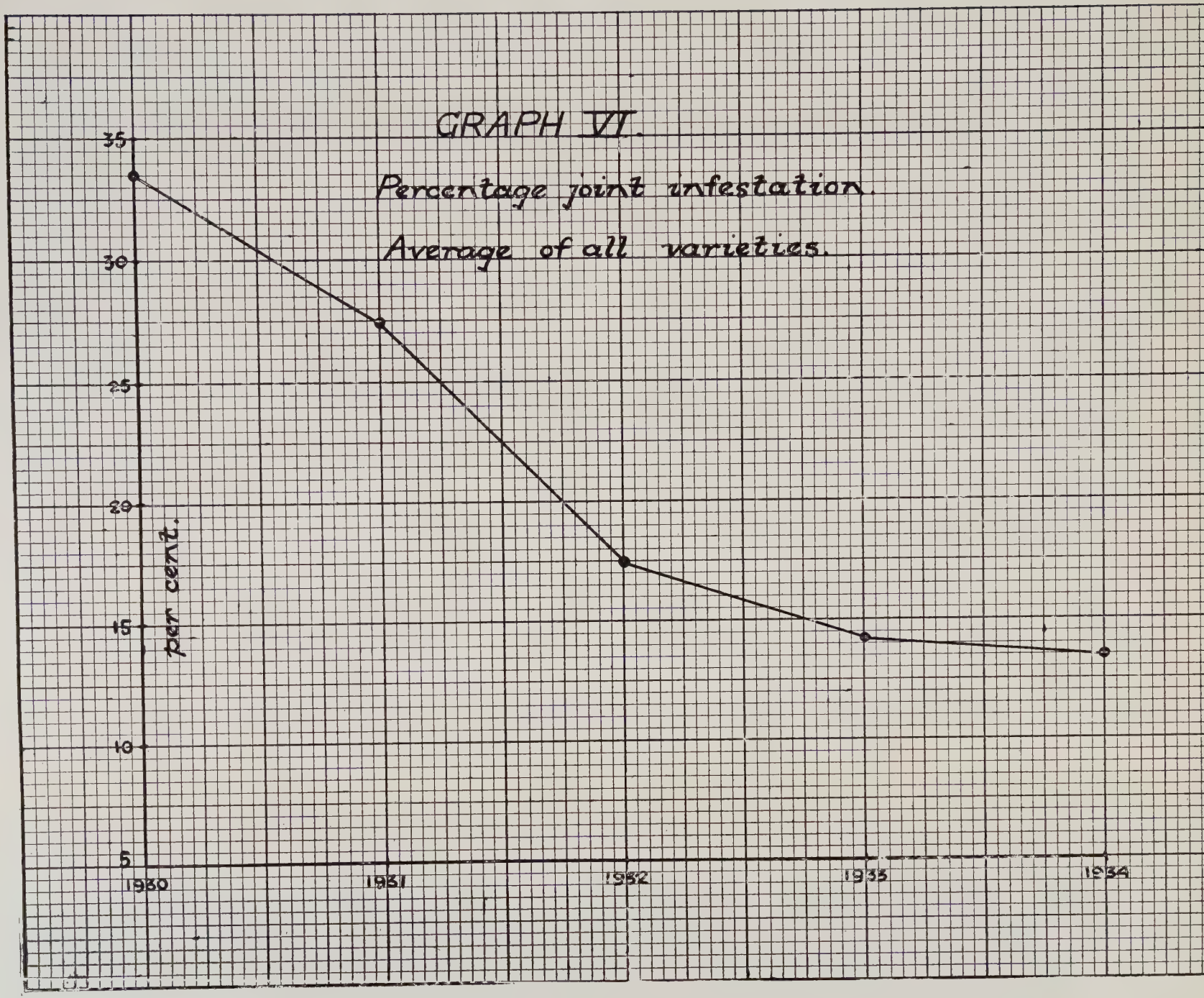
B. H. 10(12). Percentage joint infestation.

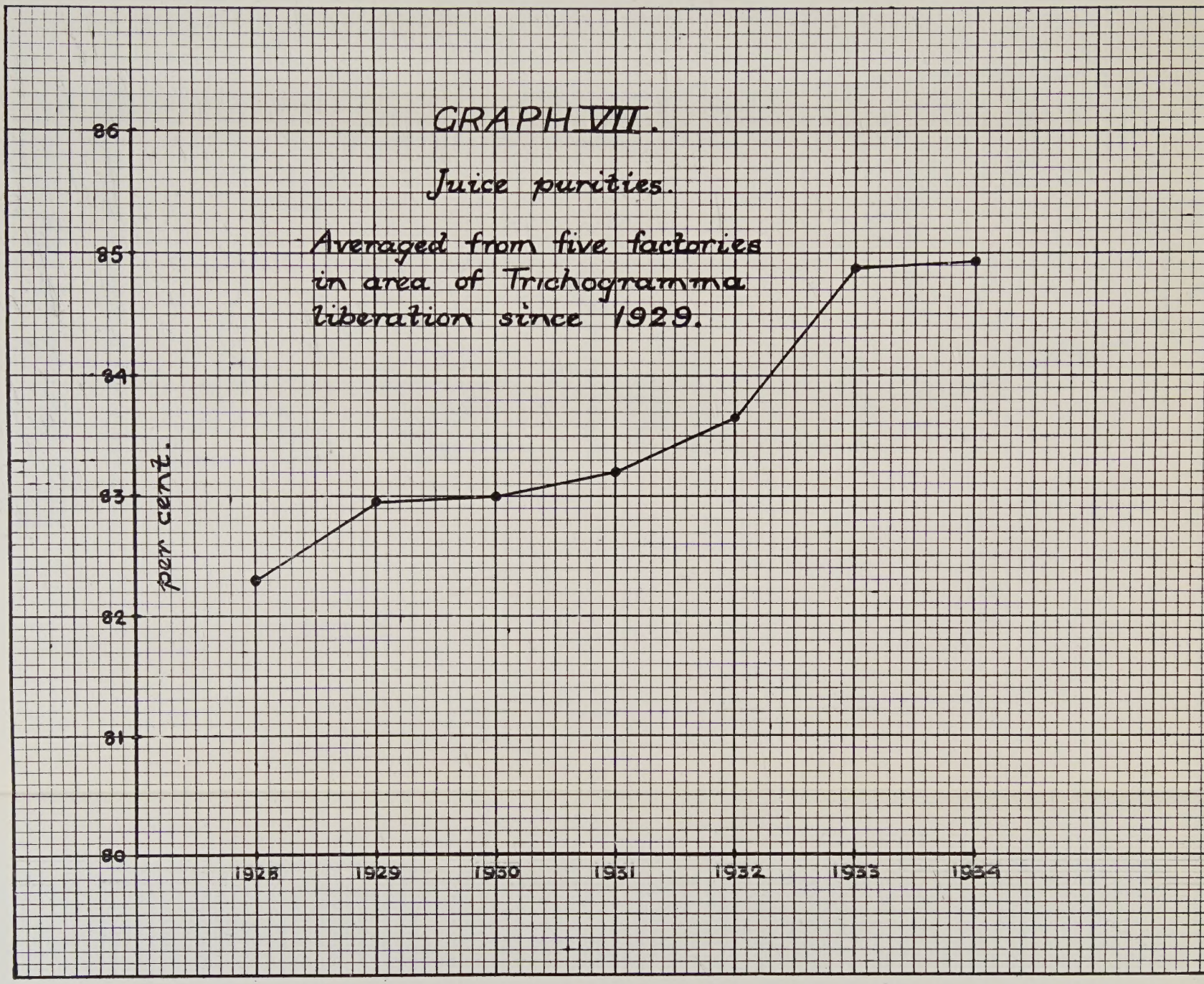


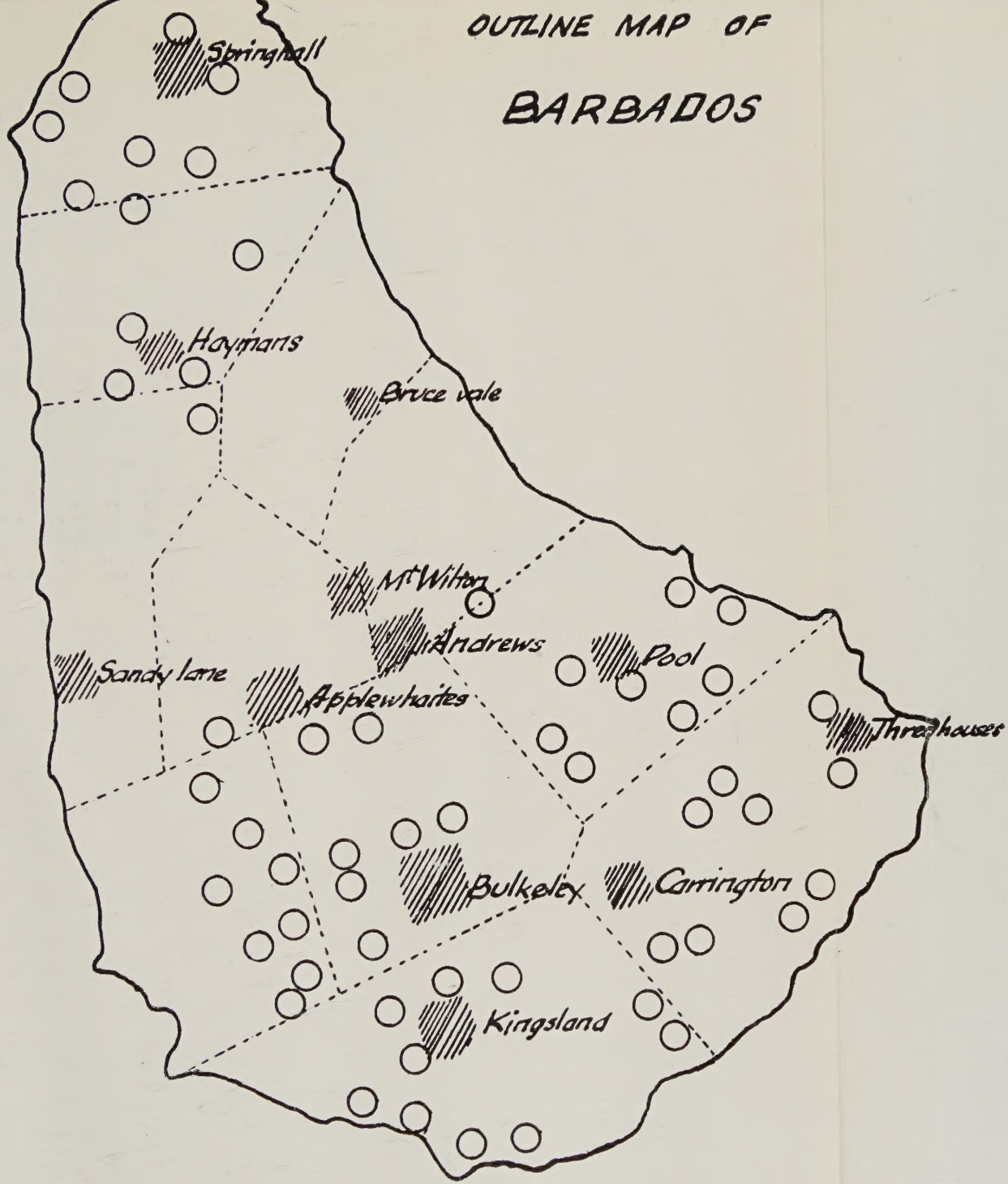
GRAPH V.

B.726. Percentage joint infestation.




GRAPH VI.
Percentage joint infestation.
Average of all varieties.
35
30
25
20
15
10
5
per cent.
1930
1931
1932
1933
1934


GRAPH VII.
Juice purities.
Averaged from five factories in area of Trichogramma liberation since 1929.
86
85
84
83
82
81
80
per cent.
1928
1929
1930
1931
1932
1933
1934



Areas covered by Cane factory samples.

Fields from each of which 100 stools were examined for total loss records.